A Concept model for Innovation Diffusion in Construction Industry

Jun Gao, Min Li, and Chor Yeng Tan

***Abstract*—**This paper investigated the innovation diffusion situation in construction industry. The main factors driving or hindering construction innovation diffusion are identified. An analysis of the relevant literature indicates there five primary influences:1) Compatibility; 2) Performance Justification; 3) Perceived Risk; 4) Organizational Variety and 5) External Influence. An concept innovation diffusion model of construction industry is built. Objective analysis and explain are made for this model.

***Keywords*—**Construction, Innovation Diffusion, Compatibility, Performance Justification

I. Introduction

INNOVATION has been given increasing importance in the business and research agenda of the leading commercial and manufacturing organization[1]. But the construction industry innovation literature contains a lengthy debate on wether or not the industry is innovative [3],[4]. Government reports commissioned in recent years have identified such problems as poor rates of investment in research and development (R&D), fragmented supply chains, and lack of co-ordination between academia and industry in research activities[5]. But an important aspect that should not be ignored is the innovation in construction industry is quite different from other industries. The construction market is highly fragmented due to the specific and specialized nature of each project. When, similar innovations which manufacturing industry adopted efficiently were promoted in the construction industry, they failed to diffuse rapidly or widely[3]. Innovations used in every project undergo constant changes, evolution and are different for every project. All these lead to a difficulty in applying the common technology diffusion models to explain the diffusion of innovations in construction industry.

In this paper, we will explore a set of structural mechanisms which will help us to build a concept model for innovation diffusion in construction industry. Main factors that influence innovation in construction industry will be identified.

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[2] Innovation diffusion in construction industry

Few papers directly explore the fundamental differences between the innovation in construction industry and manufacturing industry. Thus, few studies investigate how specific kinds of innovations diffuse in the construction industry. Innovation theory and practice always be drawn from established bodies of innovation knowledge, predominately based on other industries, but they have not been sufficiently envisioned, embedded and evaluated in a construction context to form a robust body of construction innovation knowledge in its own right[17] .

Arditi et al.[6] explored innovations in construction equipment over a thirty year period to understand the rate and types of innovations that diffuse in the construction industry. They found that innovations in heavy equipment were all incremental in nature but that the rate of introduction of new models, a proxy for innovation rate, had increased. Blackley et al.[7] looked at innovations diffusing in a population of 417 homebuilders. The results of their analysis did not support the hypothesis that the fragmented industry structure reduces the diffusion rate for innovations. Lutzenhiser et al.[8] found that the market structure impacts diffusion of energy efficiency. They found that most of innovations in the building industry were "incremental" in nature and argued that the structure of the industry inhibited innovation. However, few of these studies have considered what is the main factors driving or hindering innovation diffusion in construction industry.

II. Innovation Diffusion Model

As described in former chapter, the current technology diffusion models are inadequate in explaining the main factors which influence the adoption rate of innovations in construction project. TABLE I below summarizes the academic literature on technology diffusion models and their corresponding factors. Subsequently, these will be discussed further to establish the theoretical foundation for the innovation diffusion model of construction project.

1. Compatibility

In accordance to IDT theory, the "innovation " in the diffusion process is affected by five intrinsic attributes, namely; relative advantage, compatibility, complexity , trialability and observability[9]. Construction industry is a highly fragmented industry as the projects are often site-specific and are in accordance with the different requirements and needs. Incremental innovation of construction is the much preferred

TABLE I
TECHNOLOGY DIFFUSION MODELS

Model	Key factors
Innovation Diffusion Theory(IDT)	Relative Advantage; Compatibility; Complexity; Trialability; Observability
Unified Theory of Acceptance and Use of Technology (UTAUT)	Performance Expectancy; Effort Expectancy; Social Influence; Facilitating Conditions
Technology Acceptance Model (TAM)	Perceived Usefulness; Perceived Easy of Use
Technology Evolution and Diffusion Model(TEDM) .	Willingness to Swith; Perceived Risk; Improved Performance
Model for Systemic Innovation Diffusion	Organizational Variety; Degree of Interdependence; Boundary Strength; Span
Bass Model	Internal influence; External influence

option as it provides the flexibility and control required. This paper hypothesized construction innovations with characteristics that are more compatible with the traditional method will diffuse faster due to an easy of integration. Therefore, among the five IDT factors listed in TABLE I , the most influential and relevant one in regards to the diffusion of construction, is compatibility. Formally, this can be written as follows:

H1: Compatibility of an construction innovation with the current traditional method of construction has a positive effect towards adoption of that innovation.

In this paper, compatibility is defined as the degree whereby a new innovation is perceived to be consistent, applicable and easily integrated to the current methods of construction. In addition, this extends to the compatibility of the innovation at the social level[9],[18]. It is proposed that for construction innovation to diffuse successfully, it must not only have technical characteristics that are easily integrated but also be socially compatible with all network of decision makers, including but not limited to the client, designer,contractor and the ultimate buyers with a project.

As there are many user groups within a single network as identified above that are influenced by social compatibility will further be separated into two sub-hypotheses. The first hypothesis (H1a) will focus upon the end-user adopter.The second hypothesis (H1b) will focus upon the operational approach that conforms with the existing practices of the adopters, e.g., The designers or builders[19]. Formally, H1a can be written as follows:

H1a:The traditional method of construction has been applied for so long that this method of construction is the social norm. Compatibility with the current traditional method in being able to align with the social norm has a positive effect on adoption.

It is proposed in this paper that structures constructed using the traditional construction method are part of the social norm required by the end users or occupants of the structure. This rationale is validated by the image factor proposed by Venkatesh & Davis[20] in TAM2 which proposes that individuals are able to achieve the desired social status and acceptance within the community by behaving consistently with the status quo. In addition, the hypothesis is also consistent with the social influence factor proposed in the Unified Theory of Acceptance and Use of Technology (UTAUT) model by Venkatesh, et al.[10]. Therefore , this paper proposes that innovation in construction industry that are compatible with the social norm and the traditional method of the construction are more readily acceptable.

The UTAUT model is an integrated model that consists of a number of key ideas from established technology diffusion models in the field of information technology. In addition to the factors affecting the adoption of an innovation, the UTAUT model proposes that there are moderating variables, e.g., age, sex, experience and gender, that have an influence on the innovation adoption relationship. Nonetheless, this paper will not investigate further into these moderating variables. From the UTAUT model, we draws upon the factor of experience to complement the social compatibility factor proposed above. In adding towards the experience of the users, thus increasing social compatibility, the concepts of Trialability and Result Demonstrability will be introduced. Formally, this can be written as follows:

H1b: Trialability and Result Demonstrability of an innovation will have a positive effect on the experiences of the network of decision makers. This in turn will have a positive effect on the social compatibility with their existing values and experiences leading to a positive effect on adoption.

As defined in IDT by Rogers[9], Trialability is the degree to which the innovation can be tested and Result Demonstrability is the degree in which the immediate benefits of the innovation are observable. If the benefits are observable, there will be a positive perception on the innovation within the experiences of the users in the industry, thus increasing social compatibility for future projects, leading to a higher adoption rate.

Nonetheless, it is highlighted that the compatibility of an innovation based the context of experience can be highly subjected to interpretation[19]. To elaborate, as each construction innovations differ from each other, the experiences in its usage differ widely among the uses, making it difficult to measure and quantify.

2. Performance Justification

Technology Acceptance Model (TAM) model is proposed by Davis[12], which has been widely cited and applied in the area of user acceptance of information technology. There are two major determinants proposed for determining the “intention to use” or rather the attitude towards using the innovation. These are Perceived Usefulness(PU) and Perceived Easy of Use(PEOU).

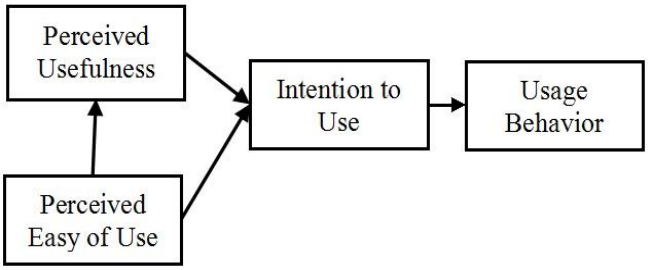

Fig. 1 Technology Acceptance Model[12]

The application of TAM is mainly in the field of information technology, where PU and PEOU were found to be highly relevant in the context of computer user behaviour due to their capability in relating to users within an organizational context. However, as compared to the situations usually investigated in TAM, the connection between each user group in the network is not as direct or clear to the adoption of construction innovation due to the existence of a multitude of decision makers.

A first principle approach whereby the theoretical foundation of the cost benefit paradigm from the behavioral decision theory will thus be applied in this paper. The cognitive decision making process undergone by network of users is found to be explained by the cost benefit paradigm. In addition, this paradigm is highly relevant to PU and PEOU. Therefore this paper proposes the factor of Performance Justification encompasses PU, PEOU and a number of sub-factors, which will be subsequently discussed below.Formally, this can be written as follows:

H2: If the overall cost of the innovation are sufficiently justified by a superior performance, then this will have a positive effect on adoption of the innovation.

Performance justification is defined in this paper as the degree to which the benefits or increased in performance of innovation justify the costs of using it. This is based on the benefit-costs paradigm and encompasses a number of factors from different models such as performance expectancy from UTAUT and the like. It is proposed that a higher perceived benefit-to-cost ratio will have a positive effect on the adoption of the innovation. Thus as implied above, Performance Justification is sub divided into two components, namely perceived benefit and perceived cost. It was argued that perceived benefits encompasses perceived usefulness and perceived easy of use from TAM and the relative advantage from IDT which is defined as "the degree to which an innovation is perceived as superior to the alternative it can potentially succeed"[9][12]. On the other hand, perceived cost does not consists of factors proposed by other models, but rather constraints highlighted by Blismas & Wakefield[2]. For example, relative capital costs, costs incurred due to a reduction in flexibility and cost of switching to the new system.

3. Perceived Risk

In order to simulate the evolution of technology diffusion through integration of a number of common technology forecasting and assessment concepts with market attributes and responses, the Technology Evolution and Diffusion Model (TEDM) was proposed by Lyneis[13]. It contains several key factors that are relevant to the construction market, in particular, construction innovations. This is due to the holistic representation of the construction industry as compared to the individualistic focus on the user group. Thus market characteristic is considered in the TEDM, which is consistent with the "macro" focus of this paper.

Furthermore, TEDM proposes the idea of perceived risk, which is the users' inherent risk aversion with regards to adopting an innovation. To further elaborate, users are generally risk averse as there exist an uncertainty in regards to the functionality of the technology or the acceptance of the technology by the wider community in the near future. In this paper, the idea of perceived risk is proposed and tailor to the construction innovation.Formally, this can be written as follows:

H3: The lower the amount of perceived risk of an construction innovation, the more positive the effect on adoption.

In the context of construction industry,perceived risk refers to the degree of risk perceived by the network of clients in the decision making process in the adoption of an construction innovation. This risk is mainly due to uncertainty involved in the adoption of the innovation and may arise from a number of sources such as the unfamiliarity of the new innovation, unexpected future costs, suitability with the other operations of the company and the market stability of the innovation. For example, if a contractor with a proprietary OSM method suffers insolvency, difficulty will arise in finding an alternative firm to complete the project. On the other hand, this issue or risk will not arise if the common traditional method of construction is used instead as replacements can easily be found.

4. Organizational variety

According to Taylor & Levitt[3], Organizational Variety is defined as the "change of contractors from project to project". It was identified that the rate at which networks of clients breaking down and reforming is very high in construction market as it is a fragmented market consisting of individual site-specific project-based activities. As such a high organizational variety occurs when different subcontractors involved in each trade in different projects exist. Thus, this paper proposes that the rate of diffusion for innovation decreases as the variety of project participants from project to project increases. Formally, this can be written as follows:

H4: The greater the organizational variety involved with a particular construction innovation, the more negative the effect on adoption.

Though the argument is applied only to systemic innovation in the paper by Taylor & Levitt[3], this paper will extend it towards incremental innovations as well. However, if the factors in systemic and incremental innovation are made equal, it is determined that this factor would have less of an impact on incremental innovation. This is because as compared to systemic, trades in incremental does not experience a drastic change in their functional system, and thus, will not oppose an strongly to the adoption of incremental innovations. For example, in systemic , the scope of work of a plumber might be completely redefined (e.g., start the hydraulics work package in a factory) as compared to the minor adjustments needed for an incremental innovation(e.g., adjusting the timing of fixtures to accommodate precast slabs).

5. External influence

In this paper, external influences are defined as influences external to the characteristics of the innovation. A few examples of this include government regulations, industrial bodies, building codes and the like.This paper proposes that external influences can produce both positive and negative effects on adoption of the construction innovation. Formally, this can be written as follows:

H5: External influences can produce both positive and negative effects on adoption.

Specifically, it was hypothesized that there would be more of a positive effect on incremental as compared to systemic innovation due to the existence of an established industrial body. This hypothesis is also found to be consistent with the facilitating conditions factor in the UTAUT model which states that given facilitating conditions for a usage of an adoption, there would be an increase in the adoption of the particular innovation[10].

By deriving these key factors from the various technology diffusion models mentioned above, The proposed Construction Innovation Diffusion Model is illustrated in Fig.2, while the definitions and source of the key factors of the model is summarized in Table II.

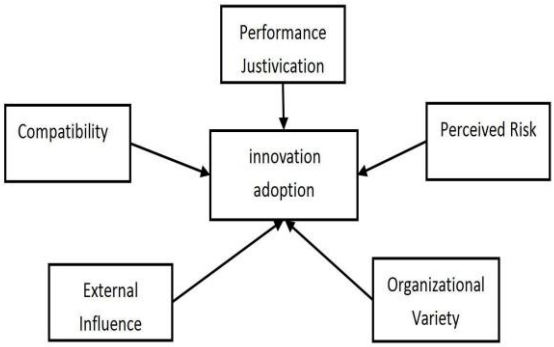

Fig. 2 Cconstruction Innovation Diffusion Model

TABLE II
KEY FACTORS OF THE MODEL

Key Factors	Sub-Factors	
Compatibility	Social Norm & Image	
	Trialability & Result Demonstrability	
	Experience	
Performance Justification	Perceived Benefits	Perceived Usefulness
		Perceived Easy of use
		Relative Advantage
	Perceived Costs	Capital Cost & Constraints
		Easy/Difficulty of Switching
		Unfamiliarity with the new innovation
Perceived Risk	Perceived Risk	
Organizational Variety	Organizational Variety	
External Influence	Building Codes	
	Regulations& Legislation	
	Peak Industrial Bodies	

In this paper, construction innovation adoption is defined as the degree of experience of an individual with incremental and systemic innovation. This is significantly different from the majority of technology diffusion models whereby a single cycle of decision-making is applied and adoption is defined as the stage where an organization or firm decides to adopt the innovation[15]. However, this definition of adoption by the other models are not applicable in the construction market due to its highly fragmented nature(individual and project-specific). As such, theres is no direct measure of the level of adoption in this industry[21]. In view of this, the actual adoption of construction innovation in this paper is thus measured based on the experience of adopters instead of a standard “yes or no” response in regards to its adoption[13]. This is based on an underlying rationale that as the level of adoption increase,the exposure of those in the industry would also subsequently increases.

III. CONCLUSION

It was found that the innovation diffusion model in construction industry was mainly consistent with existing literature and what was hypothesized. However, a few findings are found to be different from existing literature and were subsequently discussed and critiqued upon. It was acknowledged that the research has its limitation. Further analysis will base on this model, results from the survey method which will help us investigate how these factors affect the innovation diffusion in construction industry.

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