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Users-orientated evaluation of building information model in the Chinese construction industry

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ABSTRACT

In the last decade, building information modelling (BIM) has emerged as one of the most powerful dynamic decision-making tools throughout a project lifecycle, as its encapsulated information synchronises with construction practices. Many reports indicate that BIM has entered the mainstream use in some countries. However, BIM has experienced slow and limited spread adoption in other countries. We propose a comprehensive research model to examine the factors that influence the adoption of BIM. The model draws on technology acceptance model and innovation diffusion theory and is validated using survey data from the construction industry in China. The findings demonstrate that attitude, technological, and organisational dimensions indirectly affect the actual use of BIM through perceived usefulness (PU) and perceived ease of use (PEU), with PU and PEU being the primary determinants of BIM adoption. Furthermore, a striking finding was the positive influence of the attitude dimension on the actual use of BIM.

1. Introduction

The impact of building information model (BIM) adoption in the construction industry is an important topic to both academics and practitioners. Since the early 2000s, there has been a rapid growth in BIM usage for construction projects [1,2]. The technology of BIM is considered to be a powerful tool for improving design quality, construction safety and management efficiency for a construction project, which eventually obtains favourable returns to the users of the technology. In addition, the communication between project stakeholders is being altered by the introduction of BIM in the architecture, engineering and construction (AEC) industry, where BIM is facilitating the sharing of information, knowledge and technology between multiple parties throughout the project life cycle.

Since the 1970s, aerospace aviation and manufacturing industries have experienced the increasing use of information and communications technology (ICT). This is especially true in the AEC industry. When market competition becomes fiercer, new technology is more widely adopted as is associated with rewards and advantages. To cope with the challenge, BIM is progressively being introduced as an important tool and has entered mainstream use in some European countries and in the United States [3].

Many reports indicate that the BIM market will be huge, but its adoption rate in many countries is very low compared the adoption of ICT in other industries. In recent years, practitioners and researchers have started to explore the impact of using BIM technology in the AEC industry and seek to identify the key drivers and barriers of BIM implementation, which may provide valuable insights [3–11]; however, there remains a lack of understanding as to why there is a slow and limited spread of the adoption of BIM in some countries, particularly the late adopters. Therefore, the present research is based on previous research, which draws on data collected from the Chinese construction industry, the integrated technology acceptance model (TAM) and innovation diffusion theory (IDT), which is used to identify and examine the key factors associated with BIM adoption for potential users and experienced users. The study contributes to the adoption of BIM by overcoming potential obstacles, reducing the risk of failure during implementation and promoting widespread adoption.

The paper is structured as follows. In the next section, we present a review of the literature on BIM adoption and the TAM–IDT. In Section 3, we propose our research model and hypotheses based on the literature review and TAM–IDT. The research methodology and data collection are discussed in Section 4. The results of the collected data are analysed and discussed in the following sections. Section 7 provides the implications for each stakeholder and some late adopter countries. Section 8 concludes the paper with a brief summary.

2. Conceptual background

2.1. Previous research on BIM

Many industrial relations scholars believe that BIM not only enhances the patterns of collaboration but also helps increase the

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productivity among project stakeholders. It is well known that CIFE 4D CAD (McKinney et al.) was developed by CIFE (the Center for Integrated Facility Engineering) at Stanford University, which helps managers directly identify any potential problems on a construction site [12,13]. The 4D system has attracted the involvement of a large number of leading researchers and practitioners because it displayed promising potential in design, construction and life-cycle management and been expanded from several angles, such as the PROVISYS model of Strathclyde University [14] and nD modelling of the University of Salford [15,16]. A 3D to nD research project has already been undertaken by the University of Salford, and they developed a model for integrating the nth number of design dimensions into a holistic model based on the 4D and BIM concepts. The model allows users to visualise the process of a building project over its entire lifecycle and helps improve the decision-making process and construction performance, to satisfy the various project requirements [15,16]. Some scholars from Tsinghua University developed an extended 4D++ site management model (4DSMM++) [17], which supports data exchange and sharing, and enables integrated information dynamic management, optimisation and 4D simulation of the construction process. Then, they developed 4D BIM-based construction dynamic resource management and real-time monitoring systems for the design and construction phases based on the previous model [18,19]. Ding et al. [20] developed an integrated construction management system based on multi-dimensional technology for Wuhan light rail transit projects. BIM has also been discussed from several perspectives by some scholars at Tongji University [21]. A number of studies analysed the application of GIS in the BIM environments and building information models in the geospatial domain, for example, a BIM–GIS system was developed to monitor the repetitive construction progress [22]. Liu and Issa [23] investigated the feasibility of integration of the BIM and GIS in order to perform efficient operation and maintenance work. Irizarry et al. [24] presented an integrated BIM–GIS model for visualising the supply chain process and monitoring the flow of materials. In terms of business applications, the Revit and Civil 3D software products introduced by the Autodesk Company, Microstation, TriFoma from the Bentley company, and archiCAD from the Graphisoft company are mainly applied to improve the (information) management in design and construction. These professional applications are merely applied to certain stages of the project life cycle or a professional field and lack full integration and information sharing [25,26]. As a comparison, current manufacturing operations' information technology can span from internal processes out to customers and suppliers.

Researchers and practitioners have discussed the opportunities and potential benefits of BIM use in the construction industry [6,27–31]. Eastman et al. [32] in the "BIM book" describes the term BIM application as a specific use of a building information model to support a work process or work tasks by the project team, so we adopted the definition in this paper. The leading proponent of the VDC and BIM use in construction projects is the Center for Integrated Facility Engineering (CIFE) at Stanford University. Recently, CIFE published an extensive series of observations about BIM adoption in the US construction industry [3–6,33,34], which provides valuable insight. In 2007, they conducted a survey on the use of VDC and BIM technologies in the AEC industry and concluded that "… VDC is being used and significantly growing. As this growth proceeds and advances, users become more proficient and they are more likely to perceive value and thus make organisational and strategic shifts in their operations". FIATECH presents the North American perspectives about the problems of systems interoperability in the construction industry and created a roadmap that clearly describes the requirements for future construction of IT systems integration and collaboration technologies [35,36]. The surveys have demonstrated dramatic improvements in the areas of cost and scheduling in a study by Suermann [7]. The study also indicates that the stakeholders have benefited mostly from BIM in terms of improved coordination, increased design confidence and conflict detection. In 2006, the American Institute of Architects (AIA) published a report stating that approximately 16% of design and construction firms accept and use BIM, but only approximately 60% of architectural firms employing over 50 people are using any form of BIM [37]. These findings are supported in by the AECBYTES survey in 2007 [10]. To meet the requirements of special designs and green buildings, a few projects have attempted to use BIM in China, such as the Water Cube and the Bird's Nest in Beijing, the pavilions of Shanghai Expo, the city rail exchange and the mid-route of the South-to-North Water Diversion project [38]. It is worth mentioning that in the McGraw-Hill 2009 Smart Market Report on BIM adoption in China, a few case studies and approximately ten interviews with experts were completed. In this study, the parties involved in the project are mainly owners and design companies, and BIM technology was applied only to the architectural design stage, such as the collaborative design and collision detection for the Tianjin International Cruise Port and Germany Pavilion of the Shanghai World Expo [39].

Many researchers have explored and analysed the obstacle factors for BIM implementation in an effort to promote widespread adoption. According to Ning [8], there are technical and non-technical barriers to BIM adoption in Australia, but BIM technology is very promising in the AEC industry. Shen et al. [9] presented a comprehensive overview of systems integration and collaboration regarding AEC/FM and suggested that the formal standards of using BIM takes a long time to be widely adopted. Howard and Bjork [40] indicated that "The IFC's Standards are nominally supported; no one is against them but few apply them comprehensively" and demonstrated that BIM solutions appear too complex for many. The study found that property owners are less convinced that they are getting full value from the use of BIM in the construction industry. The BIM adoption research has further focused on the stakeholders and individual as the main decision makers. The report of CIFE [3] demonstrates that the impediments to further adoption of BIM technology are shifting from technical issues to personnel issues. Suermann [7] uses the six key performance indicators (KPIs) to evaluate the impact of using BIM implementation in construction projects, and surveys demonstrated that industry stakeholders' perceptions and the capital and time for software procurement and training are the main influencing factors for BIM adoption. Chelson [30] indicated that BIM usage increases the productivity, the determinants of success on BIM projects in terms of site productivity are human factors rather than technical. Organisational support has also been found to influence the decision to adopt BIM technology [4,43,44], and it will reduce the likelihood of adopting if BIM is not supported by owner or organisation. A recently published report on 2011 Building Information Modelling Survey, by the Royal Institution of Chartered Surveyors (RICS) [11], indicated that the majority of BIM uses were in the design and construction phases. Some respondents said "they did not know whether the owners were to use the BIM after completion". The important conclusion from the survey is that respondents believe that the data exchange standards are important, but there is an urgent need for better training and technical support on the use of BIM. Boland et al. [45] indicated that communication efficiency between multiple parties is important to a construction project. Similarly, a few pioneering researchers have started to observe and improve the use of BIM technologies by AEC practitioners on projects using ethnographic-action research methodology [46–48], for example, Hartmann and Fischer's [46] exploration of how three-dimensional product models support constructability review in the AEC industry. Abdelmohsen [48] adopted the ethnographic research method and interviewing with the aim of understanding the affordances and limitations in the current BIM-enabled architectural practice with respect to communicating design intent among AEC teams working in interdisciplinary collaborative environments. A succinct and clear summary of the relevant literature regarding factors influencing BIM adoption and the experiences from different case studies is presented below in Table 1. These factors discussed by