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Exploring Effective BIM Workflow Among Practitioners by Technology Acceptance Model: A Case Study on the Construction of Facade

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Abstract: Facade structure system plays an important role in modern architecture and design. Many contractors start using Building Information Modeling (BIM) to help design and lay-out façade walls in recent years. However, there are still some users refuse to accept BIM on façade construction. Therefore, we employed Technology Acceptance Model (TAM) to assess the users acceptable of BIM work flow, with using a practical case of facade construction in Chongqing Wanda City. The factors that will affect the builder's decision of whether using BIM or not when construct façade, and the relationship among them will be found via this model. Through the analysis using TAM, this research found that the direct factors influencing the completely acceptance of BIM in façade construction is the BIM quality and Result Demonstrating, and the parameter impacting the intuition engendering is the Exterior Condition. Therefore, this paper proposes a more systemic model of BIM acceptance in curtain wall to analyze the user's acceptance. The solution can also offer a reference for future research and construct on façade structure. The acceptance model has the significance that it can help to analyze the reason why users refuse to use BIM in façade construction, thus to help users accept BIM.

Key words: Façade construction, Building Information Modeling, Technology Acceptance Model, Usage intention

1. INTRODUCTION

Facade structure system are known which employ modular frame assemblies arranged in side-by-side interlocked relation and top-to-bottom interlocked relation [1]. Facade structure has a long development history in the world, and has also developed rapidly in China for over 20 years. Because of the improvement of different functions towards building and the progress of technology, façade construction has become an integrated and mature science [2]. The curtain wall is one of the most successful types of facade construction which is widely accepted among architects [3].

Complex facade system generally refers to the hyperboloid or irregular shape of the complex facade. The curved curtain wall has wide size of the sidings, complexity of the construction and installation process, tenseness of the construction period [4] Therefore, it demands high quality on the blanking

and the construction. In addition, with the escalation of curtain wall's scale and height, and the increasingly complexity of façade structure, the information attached to the curtain wall is also growing [5]. Nevertheless, the traditional method is unable to meet the inherent requirements of these kind of projects from cost, schedule, quality and other aspects. On the other hand, façade construction is a critical process in the whole project because of its high correlation with the quality of work before and after. So there are also many coworkers at different angles participate in this stage. Consequently, a more advanced technology is required to help contractors complete the construction of complex façade structure.

Using Building Information Modeling(BIM), the communication gaps can be filled and the technical challenge can be solved. Moreover, an accurate virtual model of a building, known as a building information model, can be digitally constructed [6]. Considering the 3D visibility, parameter-driven, multi-professional synergy, it is very suitable for curved auxiliary construction of complex facade to use BIM technology. With the advantages on visualization and analysis capabilities, BIM function can provide the builders enough information to obliterate the conflict, manage the construction period and control the cost of the façade more reasonable. Thus, it is necessary to use BIM in the whole construction process on façade construction and even the life cycle management of it to achieve information management.

At present, BIM has been applied in many large-scale constructions of curtain wall in China. For instance, the architectural form in Shanghai Central Building is expressed in BIM software. They used a set of forming principles and geometric formulas, reducing its wind load by 24% compared to conventional rectangular building form and saving more than 350 million yuan [7]. In the project of Shenzhen China Resources Building curtain wall project, BIM provides a more accurate process diagram. [8]. Besides, the curtain wall project of Changsha Meixi Lake International Culture and Arts Center used the GRC management system based on BIM technology, which realized the paperless acceptance and construction of 3D visual dynamic management of mobile terminal [9].

Using BIM technology in façade construction can elevate the construction efficiency. But it has to be accepted by the users first. First, it is necessary to know the process of utilization of technology. As shown in Nolan stage model, there are 4 stages when Information Technology(IT) developing in enterprise are defined as follows: introduction (Initiation), dissemination (Contagion), control (Control) and integration (Integration). Therefore, enterprise must introduce and accept the information technology before using it. Based on the Theory of Planned Behavior (TPB), Davis proposed famous Technology Acceptance Model(TAM) by analyzing the Perceived Usefulness (PU) and Perceived Ease of Use (PEU) in information technology acceptance when in the actual application [11]. By using TAM, many researchers analyzed the acceptance degree on application of IT in various industries, such as engineering, network operators, software etc. These researches and applications of this theory, however, are quite deficient in the realm of construction, especially in China.

Therefore, this paper proposes the conceptual of BIM acceptance model in facade construction，with based on the case of Chongqing Wanda City. In this paper, Section 2 reviews the theory of TAM and previous applications. Section 3 studies the practical case to help customize TAM for façade construction. Through this model, the BIM consultants could find the relationship among factors affecting the user's decision of whether using BIM or not. And how the usability, risk and other elements influence the attitude and behavior of users' s acceptance. The contribution of this paper is to establish the foundation of research on the challenge for the first step to use BIM on facade construction.

2. LITERATURE REVIEW

Generally speaking, IT covers all computers and communications related hardware and software [8]. The user's technology acceptance is a process including various aspects, composed of behavior, the intention of behavior and attitude. The behavior means actual use of IT; the intention of behavior is used to measure the degree of the willing when users implementing specific behavior (use); attitude is a reflection of the behavior of people, that is, the positive or negative feeling of individuals when using the technology. As for enterprise, there are many reasons to decide whether using Information System (IS) or not. Among them are the pressure of cost reduction, the pressure to increase production capacity and the improvement in service or product quality while the cost remains unchanged. Therefore, to research the acceptant behavior of using IT, Davis et al. proposed Technology Acceptance Model to analyze the acceptance of IT based on computer and determine the possibility of successful acceptance of the system [9]. After further development, Venkatesh and Davis extended the TAM theory, finding that social impact and awareness treatment also affect the user's acceptance, thus they proposed TAM2 [10].

Based on the Davis' theory of TAM and TAM2, the 2 main beliefs of technology acceptance are Perceived Usefulness(PU) and Perceived Ease of Use (PEU). PU refers to the degree that a target user can use the particular technology to improve his or her work performance. PEU refers to the degree that the target user believes that the technology is not laborious. In the extended model TAM2, the variables that affect the PU are further included: subjective norms, image, job relevance, etc. The intention to use proves to be an intermediate variable between technical perception and actual use [11,12].

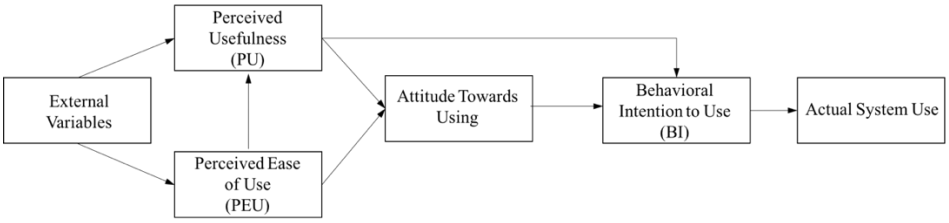

Fig.1. Technology Acceptance Model

Many researchers applied TAM in many fields of IT based on this theory. Subramanian et al. analyzed the acceptance of voice mail system and customer dial-up system through TAM [13], Gefen et al. studied the application of configuration software by using TAM on testing for effect of perceived developer's responsiveness [14]. Liang et al. [15] extended TAM, with the addition of personal innovativeness, compatibility, and support as variables, investigating the acceptance of mobile computer equipment in the health industry. They found that PU and PEU were the determining factors when deciding to actual use. Hong et al. [16] added 2 external variables on this basis, individual differences and system characteristics. Chau et al. [17] modified it to 4 main aspects: PEU, perceived long-term usefulness, perceived short-term usefulness, and behavioral intention to use.

Recent years, researchers also studied the acceptance of BIM and other information technologies used in construction. Park et al. [16] discussed the decisive factors towards the determinants of construction professionals' acceptance of web-based training through an extension of TAM, finding that the belief in usefulness of the technology was more important. In the aspect of the acceptance of BIM, Lee et al. studied the use of BIM in FM, proposing 13 factors, including 7 exterior factors, influencing the use of BIM [20]. In 2015, they advanced the BIM acceptance model in construction organizations via questionnaire, investigating of the relationship between External Variables, Perceived Usefulness and Perceived Ease of Use [21]. In 2016, Merschbrock et al. researched the BIM technology acceptance

among reinforcement workers through interview, finding that BIM technology had usefulness in promoting reinforcement works [22].

In this paper, we interviewed several participants in a case of façade construction to see the acceptance of BIM. This case is a complexed construction including different coworkers who have different attitude. So we used the Technology Acceptance Model to analyze the factors influenced attitude of users. Therefore, we can comprehend the reason why the users accept or not, and how the factors influence them.

3. CASE STUDY

To study the critical factors affecting the degree of user's acceptance when using BIM in façade construction, this paper researched the façade BIM construction in Chongqing Wanda City exhibition center project. By analyzing the main users' acceptance in façade construction and combining the additional factors with TAM, the technology acceptance model in façade BIM construction could be established.

3.1 Summary of the case

Chongqing Wanda city is located in Shapingba District, Chongqing, China, and the construction area of this building is approximately 121354.82 m^2 . The building looks like a huge camellia which is the biggest camellia building in Asia. The main structure frame is steel, and all the petals of this "camellia" is hyperboloid curtain wall. The curtain wall can be divided into two tiers: the outside tier is made by perforated aluminum plates, inside tier is made by glass curtain wall, and all of them are curved.

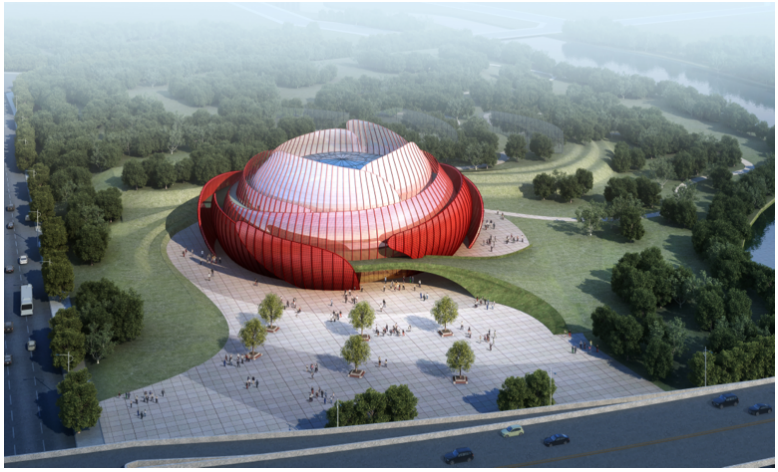

Fig.2. Chongqing Wanda City exhibition center project

In this project, the general BIM contractor is responsible for the coordination of each sub-contractor, the allocation of tasks and the transmission of model's information. Due to lacking experiences on complex curtain wall, the general contractor (China Construct on Second Bureau Decoration on Engineering CO.LTD) decided to introduce BIM team to achieve the blanking with the assistance of 3D model. The construction organization is as shown in Fig.3. Ultimately, through the application of BIM technology, they made up the delay in period of steel structure construction, and saved the cost. Besides, BIM also helped on accurate blanking, coordination of collision and quality improvement.

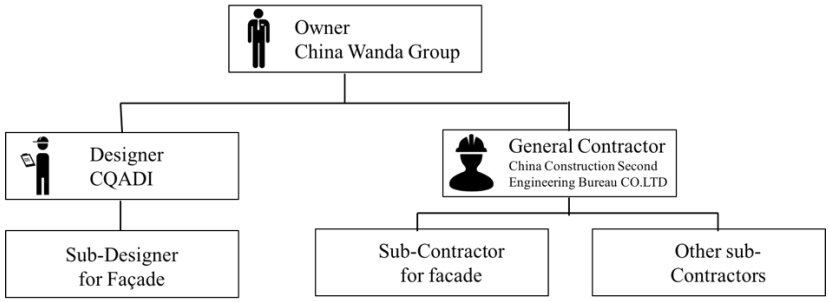

Fig.3. Construction organization

The complexity of the technics made it difficult for the façade BIM team to satisfy the need from this project and the participants. Because different participants had different degree of acceptance, there are various kind of factors influencing the acceptance of other participants to smoothly accomplish the façade construction. Thus, it is necessary for this project to use TAM to analyze the acceptance of BIM and find out which factors have impacts on the degree of acceptance.

3.2 Customizing TAM for Façade Construction with BIM

3.2.1 BIM acceptance in façade work flow

As shown in Fig.4, the general manager in China Construct on Second Bureau Decoration on Engineering CO.LTD is responsible for the total management in this case. The façade BIM team is an introduced subcontractor, and the general contractor is only responsible for the civil part. Yan Shuai, the deepening designer of steel structure, need to cooperate with the civil contractor. The façade project is the rear work for the steel structure construction and has a greatest impact on it. The coordination between the façade and steel structure project is mainly about the collision coordination, that is, the façade team should propose a corresponding optimization scheme. This scheme requires to optimize the bar and reduce the impact on appearance caused by direct intercalation of the curtain wall, or to reduce the impact of inserting. In addition, the decoration team needs to cooperate with the façade BIM team during blanking, and adjusts the façade model using their practical experience. Further, they can display the model to the installation workers to complete the construction guide.

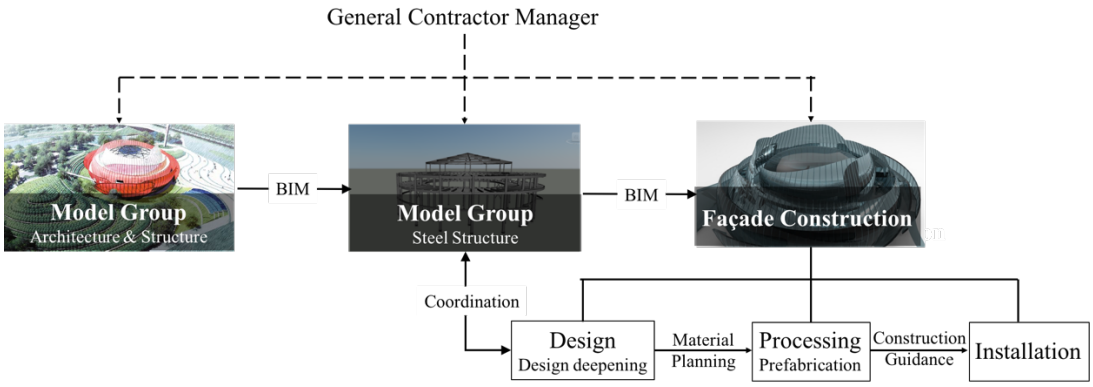

Fig.4. Façade construction BIM work flow

The participants in this case have different degree of acceptance on BIM. At the beginning, the general contractor manager has negative impression on BIM. After completing the BIM technology implementation, however, he changes his attitude and decides to use BIM in the future. Nonetheless, The steel structure's designers and the decoration team are willing to accept BIM technology, showing great interests on it.

3.2.2 TAM for façade construction with BIM

In the Technology Acceptance Model for BIM, this study assumed that the façade BIM team fully accept BIM for the reason that the team is usually a separated team and the main implementer. Based

on this hypothesis, this case studied the acceptance degree on other individuals and groups, including the steel structure team, the decoration team and the general contractor manager. The BIM technology acceptance model proposed by this study based on the TAM2 model. Nonetheless, because of the particularity of the façade BIM construction, this paper further detailing the factors, adding 3 indirect factors influencing Subjective Norm (Request of Supervisor, Belief in Benefits and Compatibility), and analyzing the factors affecting the Belief in Benefits by considering the exterior condition (including the construction conditions and the Nature of firm).

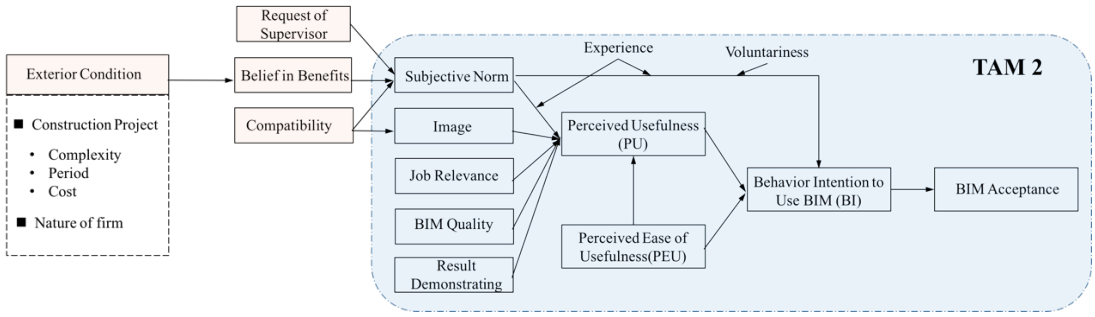

Fig.5. Customizing TAM for Façade Construction with BIM

3.2.3 Key factors for BIM acceptance in façade construction

Perceived Ease of Usefulness

PEU is defined as "the extent to which a user believes that using the technology will be free of effort" [11]. PEU has direct effect on PU and BI (Behavior Intention). In this case, the direct user of BIM is the façade BIM team. Other individuals and groups just indirectly use BIM to achieve the follow-up work, whereas the PEU is mainly aimed at the direct users. So based on the previous assumptions, the façade BIM team show fully acceptance on BIM.

Perceived Usefulness

PU is defined as "the extent to which a user believes that using the technology will improve his or her job performance" [11]. The previous researches have proved that PU has a direct effect on user's behavioral intention to use the technology [21]. In TAM2 proposed by Davis et al., the factors having direct influence on PU are *Subjective Norm, Image, Job Relevance and Result Demonstrating*.

First, *Image* represents the user's impression of the technology. When customizing TAM for this case, it could find that the Image of user using BIM is mainly affected by the Compatibility. *Compatibility* is defined as the degree to which the technology fits the potential adopter's previous experience, work practice, and needs [22]. As for the steel structure team, they deepen the design of steel structure basing on the model of civil BIM team to complete blanking, and adjust the steel structure model incorporating with façade. Compared to not use BIM, they could solve the collision more quickly and make the construction mistakes less. As for the decoration team, they could optimize the blanking and comprehend the model easier, and pass the instructions to the installation workers more quickly when compared to the previous works. As for the general contractor, he does not have contact with the BIM technology before, so he believes that BIM won't have great improvement relative to the traditional method. Therefore, it is difficult for him to engender perceived usefulness.

Job Relevance mainly depends on the relationship between the user's job and the technology. Therefore, the steel structure group is a relatively passive user when using BIM in façade construction. Façade BIM team needs to coordinate with them initiatively. In this situation, they can perceive the usefulness. The decoration team, as a follow-up work of façade design, is unable to complete the complex curtain wall's technical requirements when processing the blanking in the latter period. Besides, they fear of taking responsibility if ordering in advance. So they report that they cannot complete the

ordering and blanking unless using BIM. Thus, the perceived usefulness of the decoration time engendered.

BIM quality and Result demonstrating can be revealed after completing the construction, which are consequence bringing by the application of new technology. In this project of façade construction, the BIM quality and Result demonstrating are as follows:

i. Based on the façade Rhino surface model, the façade 3D information model can help deepen the elaborate modeling, including keel, aluminum, connectors, curved panels and other components;
ii. 3D Technical explanation for the complex installation of the façade;
iii. Simulation and demonstration of scaffolding erection and hoisting scheme;
iv. Based on the model and the construction process, the project could accurately cut the panel size.
v. Based on the optimization model, the construction can save nearly half a month compared to the traditional methods;
vi. Based on the BIM management platform, the process of the construction could achieve progress simulation control.

For the steel structure team and decoration team, BIM can greatly improve the efficiency and reduce the mistakes. The final result has the greatest impact on the general contractor because the general contractor manager is not involved in the actual implementation of BIM, and pays more attention on the result. Hence, the BIM quality and Result demonstrating are the decisive factors that make the general contractor manager finally decides to accept BIM technology and continue to use in the future.

Subjective Norm

As for *Subjective Norm*, this paper mainly based on the attitude of general contractor manager to analyze. The factors influencing the subjective norm are: *Request of Supervisor, Belief in Benefits and Compatibility*. In China, the reason why contractors would use BIM is generally related to the request of owner or the superior leaders. In the case of Chongqing Wanda City, the owners did not directly request to use BIM. So it is not limited by the owner for the general contractor to use BIM or not. Therefore, the factors influencing general contractor manager's acceptance is *Belief in Benefits*. Before the implementation of BIM, the manager is not optimistic on using BIM, thinking that BIM can produce little significance and profit. However, this estimate is based on the wrong awareness of the *Exterior Condition*. The actual Exterior Conditions of this project are as follows:

Table 1. Exterior conditions of Chongqing Wanda City

Variables	Assessment items
1.Construction Project	
Complexity	Singularly shape，huge engineering quantity; Quality and accuracy are of high demand; Harsh environment and safety condition; Difficult coordination management.
Period	Construction period is short, plan is closely arranged.
Cost	Strictly cost control
2.Nature of Firms	State-owned enterprise

The manager did not accurately anticipate the difficulty and complexity of the façade construction. At the very start, he thinks that the technical staff can solve the problem on their own. In this condition, however, the cost will sharply increase and the construction period will delay if using traditional method. Because the technical staff lack of experience to continue. Only by the means of BIM, they can solve the problem and get benefits. Besides, because the *Nature of the Firms* is state-owned enterprise, it

would lead to political failure if this project failed. Therefore, the manager begins to attach importance to the work of BIM team. Even so, the manager is still hesitant when needing him to confirm the signature in the final transactions to pass the orders to the plant. Noted that, although Belief in Benefits is an important part of the user's Subjective Norm, it could not engender high acceptance degree because the user can only predict the benefits, especially when the user absence of experience.

Thus, in this case, *Belief in Benefits*, which affects the user's decision to start using BIM, is only the first step that affects the user's attitude. The user's acceptance does not achieve the maximum until the user is influenced by *BIM quality and Result demonstrating* in the end of the project, and the user can fully accept BIM technology applying in façade construction.

4.CONCLUSION

This paper studied the BIM acceptance of users in the actual façade construction project by combining TAM model and the analysis of the attitude and its influences of users, and established a technology acceptance model applying to use BIM in façade construction. After the research, this paper could find the direct factors deciding the full acceptance of BIM in façade construction is the BIM quality and Result Demonstrating, and the element influencing the generation of behavior intuition is the Exterior Condition. Specifically speaking, in this construction, the Perceived Usefulness of the former and later users of façade BIM team mainly come from Image and Job relevance. The Image is primarily influenced by Compatibility. As for the manager of façade BIM construction, the Perceived Usefulness is mainly affected by BIM quality and Result demonstrating. The initial intention to use BIM is affected by Exterior Condition. These factors are decided chiefly by the user's job position and the effect of using BIM.

Through this study, builders can analyze the degree of acceptance when using BIM in façade construction. By analyzing in advance, the acceptance degree of BIM could be projected, and the factors affecting the user's negative attitude could be found. Further, we could analyze the weighting coefficient of each factors by researching more cases and investigating the participants. Thus, the builders can ameliorate the factors and coordinate with users, making BIM technology be accepted in façade construction.

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