

Establish a Cost Estimation Model for Pre-Sold Home Customization based on BIM and VR

S. H. Tung^a, K. C. Wang^{b*} and P. Y. Yu^c

^aMaster, Department of Civil and Construction Engineering, Chaoyang University of Technology, Taiwan

^bAssistant Professor, Department of Civil and Construction Engineering, Chaoyang University of Technology, Taiwan

^cMaster Student, Department of Civil and Construction Engineering, Chaoyang University of Technology, Taiwan
E-mail: s10811614@gm.cyut.edu.tw, wkc@cyut.edu.tw, danny310130@gmail.com

Abstract

Virtual reality (VR) has been widely applied in the construction industry, enabling users to view unfinished buildings in an immersive virtual environment. A game engine can be used to create a virtual environment with parametric characteristics from building information modeling (BIM), enabling the BIM parameters to be presented in the VR environment. This study integrated VR with BIM to facilitate modifications to an apartment. A cost estimation system for modifications was established. The proposed system can provide customers with a first-person view of possible design changes to a home, minimizing discrepancies in seller–customer perceptions. Costs for customer modifications are calculated in real time using the database and the unit price database.

Keywords –

Building Information Modeling; Virtual Reality; Cost Estimation; Presold Home Customization.

1 Introduction

In recent years, virtual reality (VR) has been widely applied in the construction industry, enabling users to view unfinished buildings in an immersive virtual environment. The use of a game engine (Unity 3D) as a development platform for creating a virtual environment [1,2,3,4] in conjunction with parametric characteristics of building information modeling (BIM) enables the parameters of building components to be presented in the VR environment. In this study, VR was integrated with BIM to facilitate modifications to an apartment. Through the combination of VR and BIM, a cost estimation model for modifications was established. The proposed model can provide customers with a first-person view of possible design changes to a home, minimizing discrepancies in seller–customer perceptions. Moreover, the proposed model shortens the time required for

calculation of change cost in traditional changing process.

2 Literature Review

2.1 Integration of BIM with VR

A BIM system contains all relevant construction data and can thus be used as a VR resource. System efficiency can be enhanced through program compilation. BIM and VR systems can be combined for design evaluation, discussion, construction, and safety evaluation and can reduce rework and improve safety [5,6,7].

2.2 Application of VR in Change Orders

Davidson et. al. [2] incorporated a BIM system into Enscape [8], which subsequently enabled them to promptly update and display the interior furnishing and design. Data from a BIM system can be used to instantly display the costs associated with design changes.

Amed et. al. [3] established a new order process to enable clients to view modified building designs through VR and augmented reality. However, in this study, changes in cost caused by modifications to the structure could not be viewed.

3 Cost Estimation Model for Changing Orders Combining BIM and VR

3.1 Establishment of BIM System

Before a constructed BIM system is imported into the VR environment for cost estimation, it must be equipped with quantity (i.e., total area) data. The following sections detail the establishment of the model and the data importation.

3.1.1 Establishment of the Model

A BIM system includes basic elements such as pillars,

beams, floors, walls, and ceilings. In addition, in consideration of the following discussion on quantity in decoration, the decorative elements must be established to acquire the calculation parameters.

3.1.2 Addition of BIM Data

To acquire the necessary quantity parameters from the decorative elements, information such as the decoration material and unit price and cost must be included in the “entity parameters” of the decorative elements. Elements involving structural changes must be marked in the “Note” field in order to facilitate the calculation of costs associated with the structural changes and decorative materials added to the VR environment.

3.2 Establishment of the VR Environment

The importation of a BIM system into the game engine in an FBX (Filmbox) file format results in the loss of render data; therefore, the system must be re-rendered in the Unity game engine [9]. Additionally, a BIM system does not include interior lighting; hence, skylight must be added manually with Unity before the light mapping calculations. Realistic lighting can thus be generated in the virtual environment, and the VR system can still perform efficiently.

3.3 Extraction of Data and Derivation of Formulas to Calculate Construction Quantity

After the connection of the BIM database to the game engine, the program can extract data from the database and create formulas for quantity calculation. Data for and quantity of each element in the virtual environment can be viewed.

3.3.1 Extraction of BIM Data

To enable instant viewing of BIM data in the VR environment, a database can be connected to the game engine after the addition of BIM data to the database. Thus, the parameters of each element in the VR environment can be dynamically accessed either upon the client’s request or for quantity calculation in the system (Figure 1).

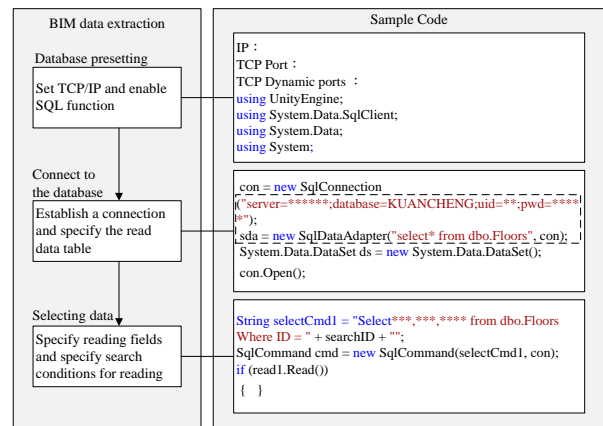


Figure 1. Structural diagram of data extraction

3.3.2 Calculation of Quantity in VR

Quantity calculations can be conducted in the VR environment by using BIM data. The database can be called according to specific requirements (such as the same ID of the component), and the parameters necessary for the element quantity calculations can be accessed when the data match the requirements. Finally, quantities can be calculated, and the results can be displayed in the VR environment.

3.4 Selection of Different Materials

The client can select alternative materials from a materials menu in the VR environment. Items in the materials menu must correspond to the materials data stored in the database, and each material can be selected from the list and applied with a single click. Hence, the client can immediately view the results of the application of the selected material. Through this method, the client and designer can reach a consensus regarding the changed elements.

3.5 Evaluation and Comparison of VR Cost Environments

A database is applied to determine unit prices. In addition, the study system uses a BIM database for the quantity data. These databases are consulted in tandem to calculate the cost of the changes. The unit price database can be based on the company's internal historical unit price database. Generally speaking, the content of the unit price database is an XML format file. Nevertheless, MS Excel can still be used for editing when the data in the database needs to be added or changed.

4 Case Study

4.1 Case Introduction

A residential building constructed in central Taiwan was used to test the system. The building has six apartments on each floor; one was selected for testing. The decorative materials and structure of the space were modified according to the client's preferences to investigate the feasibility of the proposed system. The building is depicted in Figure 2.



Figure 2. Case study model

4.2 Establishment of the BIM System

The BIM system was used to select decorative elements and to identify data required for the quantity calculations. Details are as follows.

4.2.1 Establishment of the System

Revit was used to establish the BIM system including basic elements such as pillars, beams, floors, walls, and ceilings. In addition, a new layer of decorative elements was added to the final structure of each element, as presented in Figure 3.



Figure 3. Placement of decorative elements

4.2.2 Addition of the BIM Data

“Project Parameters” comprised decorative elements; each element contained three entries as the entity parameters: decorative material, unit price, and cost. Parameter data (the name and unit price of the decorative material) were displayed by clicking on each element. For example, the decorative element “composite laminated wooden flooring” comprised the data on the floor decoration material field, whereas “1,000” (i.e., NT\$1000) was entered in the unit price field. In addition, in accordance with the client's preference to reduce the living room space, the word “changed” was entered in the “Note” field for the two walls associated with the modification. This note was a reference for later confirmation of changes in the structure.

4.3 Establishment of the VR Environment

After the BIM system was imported into the game engine, materials and light sources were added to the system. In the properties panel of the rendered model, the object was set to “Lightmap Static,” and all the light sources were set to “Mixed Lighting.” After baking, the baked lights used concurrently with instant lights were judged to create a more authentic virtual environment.

4.4 Extraction of Data and Derivation of Formulas for Calculating Construction Quantity

The element ID was used to look up data for each element as well as to calculate quantities by using the data.

4.4.1 Extraction of BIM Data

After the information from the database (shown as Figure 4) was connected with the program, the ID of each element was used to look up the data for the element and extract the parameters required for calculations of each object. For example, if the client desires to paint a wall, the decorative material, the unit price, and the number of walls would be used to calculate the total cost of the modification. For structural changes, the system automatically searches for elements with a “Note” field marked “changed.” The system can extract the “range” parameters from these elements to the database.

樓層	結構	單價	距離層的高度	分析角	標記	裝修材質	材料單價	成本
287453	1	1763.9999999...	0	3	NULL	NULL	NULL	NULL
287453	1	2044.9999999...	0	3	NULL	NULL	NULL	NULL
287453	1	2119.9999997...	0	3	NULL	NULL	NULL	NULL
287453	1	464.999999999...	0	3	NULL	NULL	NULL	NULL
287453	1	611.94477585...	0	3	NULL	NULL	NULL	NULL
287453	1	566.47687860...	0	3	NULL	NULL	NULL	NULL
287557	1	1763.9999999...	0	3	NULL	NULL	NULL	NULL
287557	1	2045.0000000...	0	3	NULL	NULL	NULL	NULL
287557	1	2119.9999997...	0	3	NULL	NULL	NULL	NULL
287557	1	464.999999999...	0	3	NULL	NULL	NULL	NULL
287557	1	566.47687860...	0	3	NULL	NULL	NULL	NULL
287453	1	611.94477585...	0	3	NULL	NULL	NULL	NULL
287557	1	611.94477585...	0	3	NULL	NULL	NULL	NULL
287557	1	709.999999999...	0	3	NULL	NULL	NULL	NULL
287453	1	709.999999999...	0	3	NULL	NULL	NULL	NULL
287453	1	1684.9999993...	1	3	NULL	白色大理石平板	900	12780
287453	1	915.0000000...	1	3	NULL	複合層木地板	1000	NULL
287453	1	1339.9999999...	1	3	NULL	複合層木地板	1000	NULL
287453	1	998.0000000...	227	3	NULL	水泥石	160	NULL
287453	1	1141.9999926...	227	3	NULL	水泥石	160	NULL
287453	1	512.0000000...	232	3	NULL	水泥石	160	NULL
287453	1	512.00000737...	257	3	NULL	NULL	NULL	NULL
287453	1	639.99294929...	1	1	NULL	NULL	NULL	NULL
NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL	NULL

Figure 4. Information from the database

4.4.2 Calculation of Quantity in VR

For the quantity calculations, the element ID and the element data from the necessary fields were first extracted. The calculation formula for each object (such as wall painting, flooring, doors and windows) was then derived. For modifications to the walls, floors, or structure, “range” parameters (means the area of the room) were used as the quantity data. Thus, the quantity of each element could be displayed in VR (Figure 5). Moreover, for structural changes, “range” parameters for walls were added to the elements marked as “changed,” and the total quantity after the living room structure modifications could be viewed in VR and was 1.2 m².



Figure 5. Parameter extraction and quantity calculation

4.5 Selection of Different Materials

In the test case, the client intended to change the living room floor material from “composite laminated wooden flooring” to “polished butter-colored marble flooring.” To change the living room floor in the VR environment, the user must simply click to open the material list (Figure 6) and select “polished butter-colored marble flooring” as the new material.



Figure 6. Replacement with material list

4.6 Evaluation and Comparison of VR Cost Environments

After changing the material and structure, the user could view the changed pattern and cost. As displayed in Figure 7, changing the living room floor from “composite laminated wooden flooring” (NT\$1,000 per unit) to “polished butter-colored marble flooring” (NT\$900 per unit) reduced the cost from NT\$14,202 to NT\$12,780. In addition, structural changes made by the client increased the space of the second bedroom, whereas the space of the living room was decreased. Due to the application of the lightweight drywall partition system (NT\$4,000 per unit), the additional cost of the modification was NT\$4,800. The calculation was the result of multiplying the quantity (1.2 m²) by NT\$4,000. Because the program could instantly display the modified pattern and the cost of the modifications, the client could immediately make comparisons and receive advice regarding the decisions.



Figure 7. Instant feedback regarding modification costs

4.7 Record of changes

The system used in the test case enabled the client to understand the modified pattern and difference in cost due to the instant changes displayed by the system. Data regarding the changes were also recorded in a text file.

The client and the construction company could use the recorded data to discuss further changes. The record of changes is displayed in Figure 8.



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changeorder - 記錄表
變更的 編號ID 修改ID 修改ID 說明ID
..now_Sum.: $ 450
..update_Sum.: $ 2030
..Total.: $ 1380
now material:水配管
now cost: $ 650
updated material:漆油仿古白橡木貼面
updated cost: $ 2030
difference: $ 1380
-----
..now_Sum.: $ 1743
..update_Sum.: $ 8177
..Total.: $ 6434
now material:水配管
now cost: $ 1093
updated material:白色大理石平板
updated cost: $ 6147
difference: $ 5054

```

Figure 8. Record of changes

5 Conclusion and Future research

5.1 Conclusion

This study proposes a cost evaluation system for building changes that combines BIM with VR. The system facilitates client modifications to both the decoration and structure of the house, in addition to estimating the costs of these changes. No previous work has proposed a system that can achieve all three of these capabilities. The client can also immediately review the changes in an immersive VR environment. Overall, the following two key achievements were obtained.

1. Use of VR to display the modified design

Easy material changes by using the developed application provides the user with multiple materials (such as wood floor, stone, or tile) to select from; the user can then easily add other decorative materials on the basis of their preferences. In addition, the virtual environment enables instant viewing of the modified design and comparisons between multiple options. Thus, the client can discuss their opinions with the designer efficiently.

2. Accelerating cost calculation for change orders

The calculation formulas in the system enable automatic calculation of element quantities and the total bill of quantities made to design elements. The client can thus immediately see the cost of the changes. Furthermore, each modification, cost variation, and total cost of changes can be recorded, and after making changes to the system, the user can provide a record to the client and the construction company when deciding whether to apply the changes. The calculation process can thus be shortened compared with the conventional calculation process.

5.2 Future Research

This study did not consider the situation of multiple users watching in the same virtual reality environment. The benefits of the discussion should be increased if designers, construction companies, customers and other parties can discuss in the same virtual reality environment at the same time. Therefore, follow-up research can take multi-person collaboration technology into consideration.

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