



## Integrating Building Information Modeling and Virtual Reality to Develop Real-time Suitable Cost Estimates using Building Visualization

S. M. Omaran, A. S. J. Al-Zuheriy\*

Civil Engineering Department, University of Technology Iraq, Baghdad, Iraq

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### ABSTRACT

The literature and previous research revealed that reducing the variation order by selecting the favorite material visually by the project's owner in the design stage is not available recently. As a problem, the cost estimates in real-time from walk-through interactions selecting multi-alternative building components are a potential threat to projects' success unless there is a visualization system helping to decide the costs of different building items and the items' suitability. This research is a powerful tool that allows the project's owner to reduce the variation order by visually selecting his favorite material in the design stage. It expresses the application of Building Information Modeling (BIM) with Virtual Reality (VR) to improve Cost Estimation (CE) and the material selection process. The authors utilize BIM and virtual reality technology to enhance the visualization and processing of project cost estimation in the construction industry. In this study, the primary goal is to develop a BIM-VR-CE system that helps construction stakeholders to visualize and quickly to decide the costs of different building items and the items' suitability. Accordingly, the authors developed a BIM-VR-CE system that integrates BIM and virtual reality technology using Unity 3D. Navigating building environments in real-time with the ability to select the cost and items suitable for elements of projects is now available to construction stakeholders through the BIM-VR prototype developed in this paper. To evaluate the effectiveness of the proposed preliminary model, a questionnaire was created, and 85 evaluations were collected. The findings of this paper show significant potential to utilize the proposed model in construction projects to deal with cost, reduce the variation orders, and select the favorite elements.

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## 1. INTRODUCTION

The accuracy of project cost estimating is one of the most important factors for the success of construction projects [1]. To determine the financial resources, resources, and scope of work, construction projects need efficient cost estimation [2]. Estimation should be considered before construction; otherwise, an incorrect approximation could lead to the failure of the project [3]. Also, the cost estimates help track the progress of development and can assist in decision-making regarding project termination [3]. Project failures have increased due to inaccuracies in cost estimation. Problems encountered in construction estimates include cost overrun, failure to initially define the scope of the work, unrealistic assumptions, lack of

estimation knowledge, poor technologies for estimation, and even inflation. At project completion, the initial costs differ by a more significant margin than expected [3].

The technological advancement in the construction industry recently created an important term; BIM, integrated with virtual reality. BIM is an illustration of the physical features of buildings that enable the making of decisions during the project's lifetime [4]. The BIM can be expanded to consider the full construction cost and scheduled activities. Initially, the contractors and building owners used CAD documents from engineers and architects. The drawings did not integrate the schedule and cost with the technology advancements that have been incorporated to reduce the costs. Therefore, using a 3D model can help contractors as well as owners

\*Corresponding Author Institutional Email:

[ahmed.sh.jeber@uotechnology.edu.iq](mailto:ahmed.sh.jeber@uotechnology.edu.iq) (A. S. J. Al-Zuheriy)

to create a 3D environment to deal with the cost and schedule of projects effectively. Also, virtual study construction of 3D modeling helps ensure a more efficient understanding of buildings. The digital models will effectively change the construction industry, especially when the visual analysis proficiencies become repetitive [5]. When clients incorporate this technology, they end up saving on the cost of the project.

There have been various studies documenting the importance of VR technologies. However, VR has not been used effectively in the design process. VR use has been limited to some projects of importance. In the recent past, this was because of a lack of computing hardware that was affordable. This meant that VR at that time needed time-consuming and costly to create different 3D models [6]. The initial design was done on a 2D model. The original design from the 2D could then be taken to the 3D model, and this had to be done by someone else. It consequently affected the integration of technology conversion to a suitable real-time optimized visualization. Therefore, utilizing BIM in the construction industry has enhanced new capabilities in construction. Evolution from the 2D to 3D models has now made it easier to describe buildings in detail [7]. Now it is easier to integrate BIM models into VR without creating a separate model.

## 2. LITERATURE REVIEW

Virtual Reality (VR) has numerous applications in construction [8]. It has the potential to navigate freely in 3D models. It communicates ideas ideally regarding upcoming projects and enhances understanding of tasks in a detailed manner [9]. For individuals with fixed experience in interpreting ancient designs, the VR helps avoid misunderstandings that can arise and helps enable a thorough comprehension of all buildings [10]. The BIM method can maintain and generate all the information produced during the construction process from design to maintenance. The prototyping supports the solicitation of the BIM data in developing several multi-dimensional BIM models. It also hastens the process of delivering and refining designs [11]. The nD-BIM applications are described below.

a) 3D-BIM model involves modeling the development of architecture, piping, and electrical [12].

b) The 4D-BIM model relates to construction planning and scheduling. Also, it supports the visualization of constructing, monitoring, and controlling the project. 4D-BIM mode is achieved by links from the 4D application with the 3D elements such as links between Naviswork and Revit to visualize the schedule of the project [13].

c) The 5D-BIM model is mainly related to cost estimation [14].

d) The 6D-BIM model is related to energy and sustainability. It is used to estimate the energy consumption of the project, and to measure and verify energy utilization in the life span of a building [14].

e) The 7D-BIM model is used to support facility management and maintenance activities [15].

Communication among individuals at a high - level comes from data design. From existing reports, many companies recorded quick project approvals, increased workers' interactions, and enhanced productivity. For efficient work of the BIM technology, the software combines other advanced technologies like Virtual Reality (VR) enhancing defect analysis and management. Linking the VR and BIM blends expertly to the design of the BIM. The process improves architecture and engineers' activities in construction [16]. The VR blends with additional fields that aid the use of visualization recognized by the BIM. This study examines the number of accomplishments permissible by the genuine software to execute numerous tasks merging VR and BIM, primarily in two indispensable uses: the 4D model aiding building activity and the 7D model regarding building conservation [16]. In the distinct building segment, VR and BIM knowledge lead to main players' upgraded communication, grounded on the visualization of superior design, relevant to the best indulgence of the augmenting BIM blend with VR. The reality of different data that can be related to other factors which classify every single BIM progression is of immense significance once the workers want to investigate hitches and deliberate alternate solutions [16]. The simulation of the life-cycle cost (LCC) supports by integrating BIM and the game engine model. To envisage LCC analysis, owners, stakeholders, and students depend on the BIM-game prototype [17].

Combining the BIM and VR models to help visualize the characteristics of the sorts and access to information is an evolutionary improvement of the entire project. Approval of virtual reality in the building field has risen. VR facilitates the operator to engage in a 1-to-1, 3D, and BIM scale with significant influence [18]. To view designs earlier for customers, construction experts are aware that virtual reality apps are making it possible, thus lowering material costs and shrinking the total number of laborers required for a specific project. Alternatively, the BIM/4D model the VR can help BIM methodology given that it permits the user to interact with 3D and BIM models in two important ways [18]:

a) A walkthrough is popularly used because it enables the user to use 3D in a completely simulated environment from numerous buildings, whether inside or outside of the building [18].

b) Consulting data is concerned with the possibility of retrieving the data already centralized in the BIM model that is composed of the parametric steps involved in the modeling.

In the walkthrough, the building viability can be tested by using human judgment and scale models. However, judgment cannot always be accurate. In VR, the final model can be expressed in 3-D. The user is now allowed to observe an artificial environment which is enhancing architects' efforts [18]:

- Samsung Gear VR is a VR that enables exploration of the virtual environment at construction sites or in meetings. A BIM model is required along with site pictures to allow follow-up of construction [19].

- Oculus Rift is enabled with interactive capacities that can be executed as a plugin in Revit. It can provide a realistic overview of the actual scale of a building that was not possible with traditional systems [20].

In consulting data, the model VR materials such as the furniture, and other small details are incorporated.

- Autodesk 360 permits a combination of the group in joint projects because each adjustment in the BIM model is demonstrated at a convenient time for every individual to view. Autodesk produces a comprehensive web-based clarification for studying BIM composition [21-24].

- Augment software allows the operator to realize the 3D/BIM model from a human viewpoint. It can as well be downloaded on a Smartphone to help in consultation about the BIM data [22-25].

Construction design 4D CAD models incorporate 3D components with time. They have been widely used in construction phases and have shown benefits in some activities with stakeholders like evaluating project constructability as well as, ascertaining spatial conflicts in construction [23].

The administration and conservation 7D model merging BIM with VR help enable efficient collaboration because the information can be envisioned, referred to, and distorted while the client and even the team are inside the building. The use of BIM in material estimation, labor, and cost of construction equipment will help to estimate the value of projects and any other costs accurately. Students studying BIM estimation are more prepared for the daily changing building industry. It will also help boost the technological know-how and help them stay relevant [23-26].

Using Building Information Modeling (BIM) capabilities, A novel method was proposed to identify cost and energy-efficient building envelope materials within a region over the life cycle. By replacing conventionally used materials with the available high-performance building materials, the results showed 31% and 28% for the potential energy performance enhancement and a life cycle cost improvement, respectively [27].

To minimize the expected project cost, time, and risk as well as to maximize the expected quality, a set of project activities were selected to be stopped in such a way as to reach the abovementioned goal through executive each project activity in a specific mode [28].

Building Information Modeling (BIM) and Virtual Reality (VR) are two technologies that have been increasingly used in the architecture, engineering, and construction (AEC) industry. BIM is a process for creating and managing digital building models, while VR is a technology that allows users to experience a digital environment as if it were real. The integration of these two technologies has the potential to enhance collaboration, communication, and decision-making in the AEC industry.

Ghanem [29] found the use of VR technology in particular can provide a more immersive and interactive experience for project stakeholders, which can improve the understanding of the building and the design process. However, the study has not considered all possible factors and challenges that may affect the integration of BIM and VR in the construction industry

Abbasnejad et al. [30] presented a research on how to use BIM and VR technologies for construction project management. In their study, found that the integration of BIM and VR can improve the management of construction projects. However, the study has a limitation in that the research was conducted on a small scale and the results may not be generalizable to other projects or situations [30].

Sampaio [21] discussed about the potential benefits of integrating virtual reality (VR) technology with building information modeling (BIM) methodology, such as improved communication, collaboration, and visualization. However, it may also mention some of the challenges and limitations of using VR in BIM, such as lack of standardization, user adoption, integration with other systems, and challenges in terms of implementation, cost, and availability of VR technology and software [21].

Kamari et al. [31] focused on the advantages of using BIM-enabled VR technology in this context, such as improved visualization, collaboration, and communication, as well as the ability to simulate and analyze different scenarios. It could also potentially demonstrate how the use of BIM-enabled VR technology can lead to more sustainable building design and construction and improved cost-efficiency. However, the limitations of this paper were less explored interactive characteristics with VR due to the lab shutdown and the project cost being unavailable such as indirect costs, direct costs, and other costs that could affect the decision-making [31].

Natephra et al. [32] investigated on how to use BIM and VR technologies for construction site safety planning. The study found that the integration of BIM and VR can improve the effectiveness and efficiency of safety planning. However, the study has a limitation in that the research was conducted on a small scale and the repeated lighting design processes were limited in the software and this software needs special knowledge and technical skills to handle the models [32].

This research is an effective tool that allows the project's owner to reduce the variation order by visually selecting his favorite material in the design stage. This study is unique from previous research because no other study has attempted to integrate cost estimating with the game engine and produce the (5-D) environment. Also, this paper appropriates an open game platform that helps owners, stakeholders, and students create their cost estimates in real-time from walkthrough interactions selecting multi-alternative building components.

### 3. METHODOLOGY

This study has a methodology that can be integrated with BIM with VR in 5 dimensions (i.e., 3D, time, and cost) for estimating project cost. Therefore, the project owner can use this system to navigate each item's cost in his project through VR visually. Figure 1 illustrates the BIM-VR system supporting project cost-estimating (CE). The BIM-VR-CE system included two main phases. BIM is the first phase that used AutoCAD, SketchUp, and Revit software to design 3-D models. The Revit software is utilized to create the project and accessories of the project (i.e., fences, trees, and furniture). All these 3-D models are running under the unity game engine software. These 3-D models have geometric information such as scale, and dimensions, and non-geometric details such as material types that be used internally and externally for the project. material types cannot be recognized by the Unity game engine unless they are not modified to the standard material types. The 3D-model files are exported to FBX files by using SketchUp or Revit software. The FBX file is opened through 3Ds Max software. The project materials are transformed into standard material types by using 3Ds Max software and then exported to FBX files. Also, it creates a database for all elements of the building. The process of creating the database is started by exporting the 3D-Models to an IFC file using SketchUp or Revit software. the IFC extracts the properties of each element (i.e., Absorptance, area, assembly code, assembly description, base extension distance, base offset, family name, length, extension distance, top offset, type name, unconnected height, and width). Also, it adds the cost estimate for each element and then adds the element alternatives and their costs to the database.

The second phase is VR. First, by using the Unity game engine imported the FBX file that was created by SketchUp or Revit software. then the real environment is set up for the project such as collision, gravity, and detection. Also, for navigating the project is set up the first-person controller is represented as the project's owner. To complete the virtual reality environment for the project, some game components are added to the project (e.g., land, cameras, streets, and lights). In this phase, C# scripts language is utilized. Developing a

database with C# scripts allows the user to see the properties of the element when he looks at the element. Figure 2 shows the pseudo-code of developing a database. The C# script programming is utilized to allow the owner to select various material types for any element in the project. when this change occurs properties and cost estimates of the element are changed and calculate the difference in costs between the original element and the new element and save for the final step (i.e., Report).

Figure 3 shows the pseudo-code of changing materials, and properties and estimates the cost. It uses C# scripts to create the shaded element when the user looks at the element using the VR device to allow the user to select the right element. Once the users are satisfied and made their decisions, they go to the finish button to get the report; otherwise, all cost-estimating options can be iterated by the users until satisfaction is reached. To create the final report on the computer by the users, The C# scripts are used. The pseudo-code for creating the report is shown in Figure 4. The user can find the report on the computer in a specific folder. The report includes the final decision made by them such as the names of elements that were changed with new elements, the name of the new element, the estimated difference in cost between two elements, the total of all differences in costs, and the total cost of the project after the changes. These data are collected from previous steps. The report goes to the designer to make the changes in Revit, SketchUp, or AutoCAD.

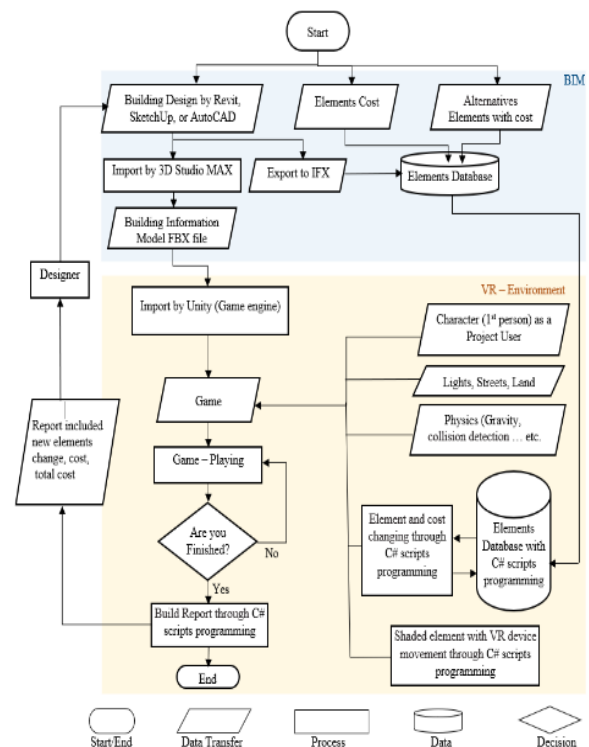


Figure 1. BIM-VR prototyping supports the process diagram for estimating costs

```

BEGIN
string d
case select element name #1
Output Display d = element descriptions "Absorptance, Area, Assembly Code, Assembly
Description, Base Extension Distance, Base Offset, Family Name, Length, Top Extension
Distance, Top Offset, Type Name, Unconnected Height, Width, Element Cost, Total cost.
break;
case select element name #2
Output Display d = element descriptions "Absorptance, Area, Assembly Code, Assembly
Description, Base Extension Distance, Base Offset, Family Name, Length, Top Extension
Distance, Top Offset, Type Name, Unconnected Height, Width, Element Cost, Total cost.
break;
.
.
case select element name #n
Output Display d = element descriptions "Absorptance, Area, Assembly Code, Assembly
Description, Base Extension Distance, Base Offset, Family Name, Length, Top Extension
Distance, Top Offset, Type Name, Unconnected Height, Width, Element Cost, Total cost.
break;
END

```

**Figure 2.** The pseudo-code of developing a database

```

BEGIN
String GameObject alternative 1
String GameObject alternative 2
.
.
String gameobject alternative n
double a1
double a2
.
Private double an
Onmousedown
Display alternative texture and description
Hidden all other alternative textures and descriptions
If index.name = element 1 then
If Display existed element then a1 = 0
Else if Display alternative1 then a1 = cost of alternative1
.
Else if Display alternative1 then a1 = cost of alternative n
Open File
Write File (alternative name + " instead of " + existed element name + a1)
Close File
Open File
Write File (a1)
Close File
End if
If index.name = element 2 then
If Display existed element then a2 = 0
Else if Display alternative1 then a2 = cost of alternative1
.
Else if Display alternative1 then a2 = cost of alternative n
Open File
Write File (alternative name + " instead of " + existed element name + a2)
Close File
Open File
Write File (a2)
Close File
End if
If index.name = element n then
If Display existed element then an = 0
Else if Display alternative1 then an = cost of alternative1
.
Else if Display alternative1 then an = cost of alternative n
Open File
Write File (alternative name + " instead of " + existed element name + an)
Close File
Open File
Write File (a3)
Close File
End if
END

```

**Figure 3.** The pseudo-code of changing materials, properties, and estimating the cost

#### 4. IMPLEMENTATION

The application of this study is designed to utilize VR for cost estimating of projects in a 5-D environment. The

```

BEGIN
string sa 1
string sa 2
.
.
string sa n
string ma 1
string ma 2
.
.
string ma n

OnMouseOver
sa 1 = Read File 1
sa 2 = Read File 2
.
.
sa n = Read File n
ma 1 = Read File n+1
ma 2 = Read File n+2
.
.
ma n = Read File m

OnMouseDown
Open File
Write File (" Report of changing materials and cost" sa 1 + sa 2 + ... + sa n)
Write File ("The total differences in cost=" ma 1 + ma 2 + ... + ma m)
Write File ("The Total Project cost = " exist total cost + ma 1 + ma 2 + ... + ma m)
Close File
END

```

**Figure 4.** The pseudo-code for creating the report

BIM-VR is required when the project's owner needs to realize how the cost estimates influence the project. A VR device (i.e., Oculus Rift headsets + Joystick) is used to allow the client to navigate his project, and change any element in the project, as shown in Figure 5. There are many users had navigation capabilities which include forward and backward movement as well as turning right, or left, and jumping. The project's owner also interacts with the environment in real time. He cannot penetrate the wall of walls because of the activation of collision detection through the game engine. When the player walks into his project, he or she can deal with many alternatives for building, materials, furniture, or landscape. He can just look at any object and click it, the object will be changed, and its cost and feature will change simultaneously. The system can work under the Microsoft Windows system, the Xbox One system, the IOS system, and the Android system. the users used real building and put in the system and then made their decision. The results of using the system, the projects were less cost and better finishing selection, and fewer variation orders. There are four applications in this study.

In the first implementation, the project's owner can change the project's accessories such as gates, fences, landscape, and so on. The user puts on the VR headset



**Figure 5.** The user navigates the project with Oculus Rift headsets and Joystick devices

and looks at the construction accessory; simultaneously, it is shaded. the properties appear as information in the upper left corner, and then the client clicks on the construction accessory. The construction accessory is switched with an alternative construction accessory, and the information in the upper left corner informs the user of the new properties, the cost estimate of the construction accessory, and the total cost of the project. For example, the project's owner walks to the gate and looks and clicks on the gate. He or she can select from three different alternatives. The selections under each replacement are gate type (i.e., wood gate, steel gate, and modern gate), and the properties (i.e., height, length, material, cost per meter, and total cost), as shown in Figure 6.

In the second implementation, the project's owner can change objects in the landscape for the project such as a flower garden, garden shed, trees, children's play set, and so on. The player looks at an object, simultaneously the object is shaded, and the properties appear as information in the upper left corner, and then the client clicks on the object. The object is switched with an alternative object, and information in the upper left corner describes the new properties, cost estimate of the object, and total cost of the project. For example, the project's owner walks to the trees and looks and clicks on the trees. He or she can select from three different alternatives. The selections under each replacement are tree type (i.e., Palm, ForestVision\_Lite\_tree, and Pond pine), and the properties (i.e., Height, radius, cost each, number, cost, and total cost), as shown in Figure 7.

The most important application is the third application when the client wants to change elements in the building, like exterior walls, interior walls, stairs,

roofs, and so on. The player looks at an element and simultaneously it is shaded, and the properties appear as information at the upper left corner, and then the client clicks on the element. The element is switched with the alternative element, and information at the upper left corner describes the new properties, cost estimate of the element, and total cost of the project. For example, the user moves to the front of the exterior wall, interior wall, and floor and looks and clicks on them. He or she can select from four different alternatives; a click shows each alternative. The selections under each replacement are exterior wall type (i.e., Exterior\_Brick\_on\_CMU\_30\_[236056], Exterior\_Stone\_siding\_on\_CMU\_30, Exterior\_Stuccosiding\_on\_CMU\_30, and Exterior\_Aluminumsiding\_on CMU\_30), the properties (i.e., Absorptance, area, assembly code, assembly description, base extension distance, base offset, family name, top extension distance, top offset, type name, unconnected height, width, cost, and total cost) as shown in Figure 8(a). The options under each alternative are interior wall type (i.e., Interior\_-\_4\_7/8\_inch\_Partition\_(1 - hr)[248137], Interior\_Marble Texture Wall Mural, Interior\_Slate Wall Mural, and Interior\_PVC Leandros EnduraWall Decorative 3D Wall Panel), the properties (i.e., Absorptance, area, assembly code, assembly description, base extension distance, base offset, family name, top extension distance, top offset, type name, unconnected height, width, cost, and total cost) as shown in Figure 8(b). The options under each alternative are exterior wall type (i.e., Generic\_-\_12\_inch\_10\_[458745], Wood Flooring, Terrazzo (Marble Chips) Flooring, and Marble Flooring), the properties (i.e., Absorptance, area, assembly code, assembly description, thickness, elevation at bottom, elevation at

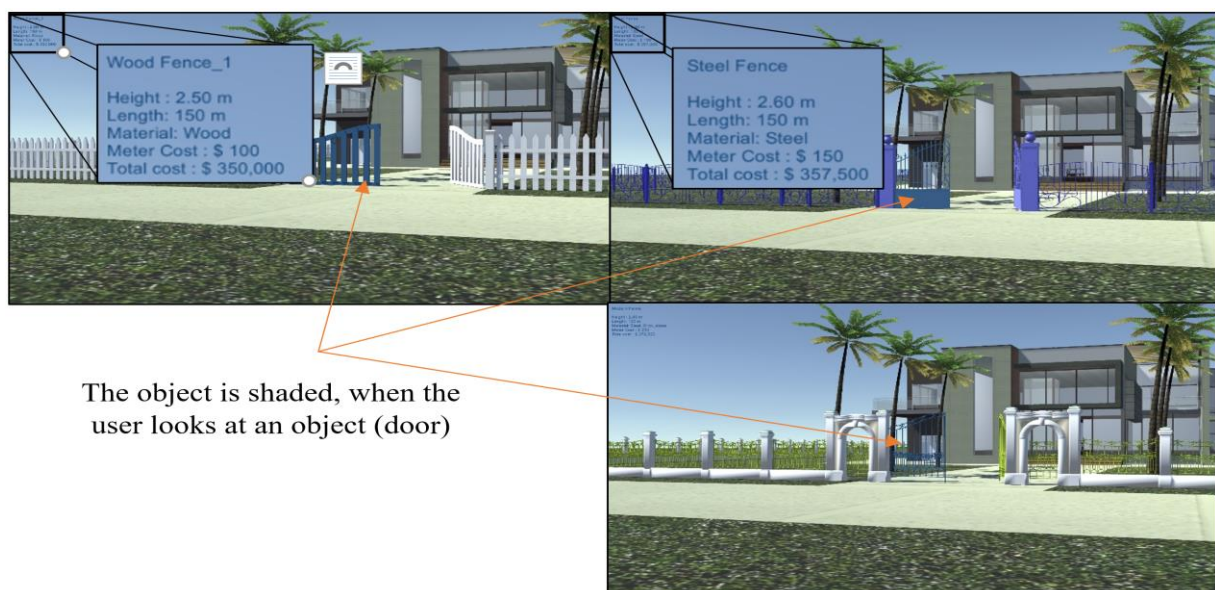


Figure 6. The first application shows the three alternatives for the fence

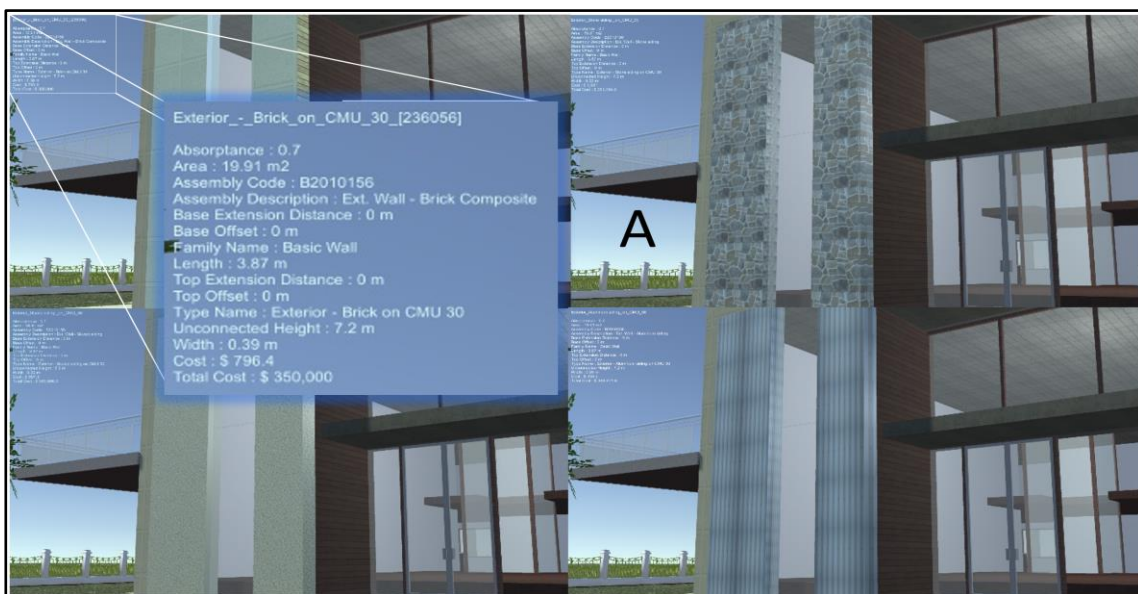


Figure 7. The second application shows the three alternatives for trees

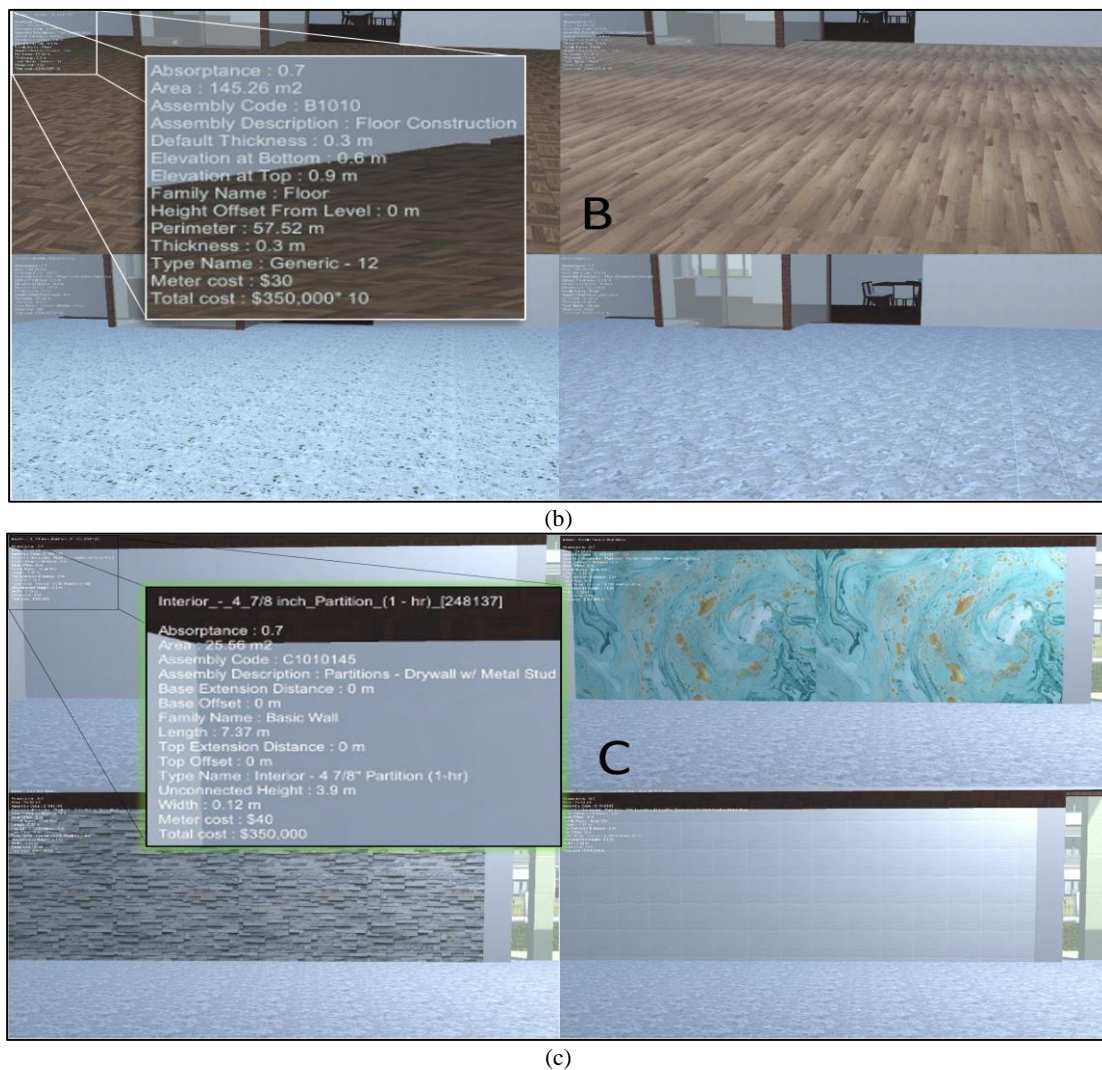
top, family name, height offset from level, perimeter, thickness, type name, meter cost, total cost) as shown in Figure 8(c).

The fourth application is when the client wants to change the furniture in the buildings like kitchen furniture, sofas, dining tables, bedroom furniture, and so on. The user looks at an item of furniture; simultaneously the furniture is shaded, and the properties appear as information in the

upper left corner, and then the client clicks on the furniture. The object is switched with alternative furniture and the information in the upper left corner informs the new properties, the cost estimate of the furniture, and the total cost of the project. For example, the user walks to the dining table and looks and clicks on it. He or she can select from four different alternatives.



(a)



**Figure 8.** The third application shows (a) the four exterior wall alternatives (b) the four interior wall alternatives (c) the four-floor alternatives

The selections under each replacement are dining table type (i.e., Height, length, width, shape, number of Chairs, material, cost, and total cost), the properties (i.e., Height, radius, cost each, number, cost, and total cost) as shown in Figure 9.

Once the users are satisfied, they go to the finish button outside the project and click on it. The system tells them the location of the report on the computer, as shown in Figure 10. The users send the report to the designer or project manager to improve the project. The validation of this system is used by many users and they gave their notes about the system. The authors update the system according to the users' notes.

## 5. THE EVALUATION OF RESEARCH

The evaluation of any application is essential to give designer feedback. In this research, the evaluation

questionnaire including five questions was created. The 5-point Likert scale (“5” Strongly Agreeing and “1” Strongly Disagreeing) was used to create the questions for the questionnaire. The BIM-VR-CE system was presented to the stakeholders. They were excited to experiment with the system. As a result, all participants finished the questionnaires. The participants who are complete the questionnaires are 85. Therefore, the size of the sample was 85 questionnaires. They used Oculus Rift headsets and Joystick devices individually to navigate the project before they responded to the survey questions, as shown in Figure 5.

The survey results were received, and all participants answer the questionnaires. the results of the analysis of the quantitative questionnaires are summarized in Table 1.

Before the analysis and discussion of the results of the evaluation, the chart of feedback results is created as shown in Figures 11 and 12.





Figure 9. The fourth application shows the four table alternatives



Figure 10. The final report process

TABLE 1. Results of quantitative questionnaires analysis

Question Description	Sample Size	Response Level (1 to 5) (%)					Average
		Strongly disagree	Disagree	Neutral	Agree	Strongly agree	
1- The simulation increased experience about estimating cost	85	0	0	12	36	37	4.29
2-The design of the simulation was easy to understand	85	0	0	3	18	64	4.72
3- The simulation reduced the change orders	85	0	0	6	23	56	4.59
4- The simulation enhanced my visualization experience about cost estimating	85	0	0	13	21	51	4.45
5- the simulation improved decision-making of cost estimates for future projects	85	0	0	16	35	34	4.21
Total	425	0	0	50	133	242	4.45

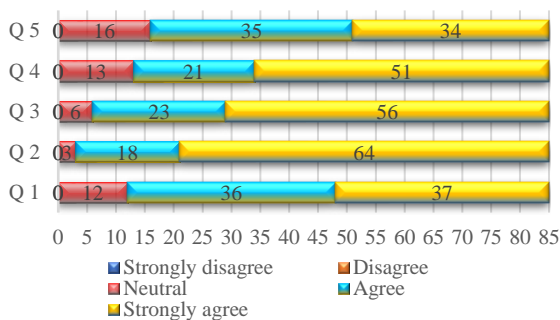


Figure 11. The feedback of the questionnaires

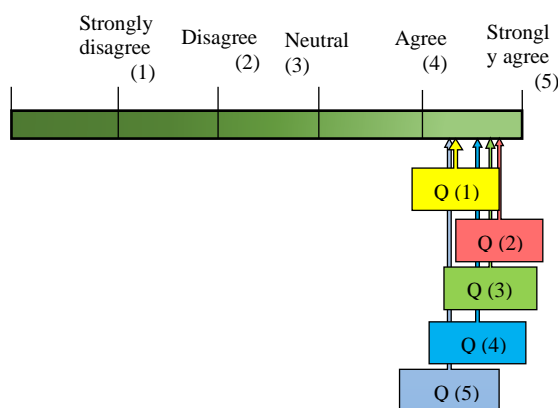


Figure 12. Questions Average

For question 1, the responses of participants were in a very good area, and the average of results is 4.29. That means the experience improved regarding cost estimates for participants. For question 2, responses showed an excellent result, and the average of results is 4.72. About 94% of the responses got positive feedback, indicating the simulation was easy to use and learn. Question 3 had a fantastic responses domain and the average of results is 4.59. This result indicates that if this system is used in any project, it will contribute to reducing the number of change orders. Question 4 as well as got an excellent value, and the average of results is 4.45. That means, the system enhanced the participants' realizing how the cost estimates for many element alternatives can affect their projects. Finally, question 5 had a very good evaluation, and the average result is 4.21. that indicates the shareholders improved their decision-making regarding cost estimates for future projects. All questions questionnaires got satisfaction, and the average is mean of 4.45, and the average result had a positive response of 89%.

## 6. DISCUSSION AND LIMITATION

The proposed BIM-VR system is found to be capable of assisting construction stakeholders to understand the art of

cost estimation promptly and accurately. Also, it helps minimize costs through creates a 3D project model that can well be analyzed, and cost estimates made accurately. Through the participant evaluate the BIM-VR system, construction stakeholders found it easy to use. Moreover, the BIM-VR system is improved and enhanced their experience and decision-making regarding cost estimates, and it can be utilized to decrease the number of variation orders. The BIM-VR system can be applied to any project, building, or element in the building and it can give the owners satisfying element selection within a suitable cost. On the other hand, the BIM-VR system has limited alternatives for elements in the project. To solve this problem, we can use all possible alternatives for elements dependent on element important that can be defined by the owner.

## 7. CONCLUSION

1. In this research, the integration between BIM, VR, and CE was developed and presented. BIM, VR, and CE are working under the game engine to enhance visualization and educate students about project cost estimates.
2. The study provided the project's owner with a system that can interact with the real-time environment for cost estimating, creating a first-person view with a VR device, as well as street, land, and lighting were created to develop realistic surroundings.
3. The programming (i.e., C# scripts) was used to create a database that interfaces between project elements and the user, to change elements, properties, and cost estimates simultaneously. The programming is also used for creating the shaded element when the user looks at it and developing a report to inform the stockholder about the changes that occurred through using the system. The BIM-VR-CE system allows the integration of many components including building modeling information, virtual reality, cost estimating, navigation, and animation through using Autodesk software and Unity game engine.
4. The benefit of the BIM-VR-CE system has supported the decision-making of owners regarding cost estimating and minimized the variation order. Also, it is supported cost estimation education by implementing a platform that allows various cost estimates of projects to be evaluated through game playing.
5. A questionnaire was generated to evaluate the effectiveness of the BIM-VR-CE. The questionnaire result indicated that the BIM-VR-CE system could be used and understood easily. Also, the visualization and the knowledge regarding cost estimating are enhanced for participants. BIM-VR-CE system can be used to promote decision-making concerning cost estimates for future projects. additionally, the BIM-VR can be used

to reduce the number of variation orders. The overall BIM-VR system had excellent satisfaction from participants.

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**Persian Abstract**

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**چکیده**

منابع علمی و تحقیقات قبلی نشان داد که کاهش ترتیب تغییرات با انتخاب مواد مورد علاقه به صورت بصری توسط مالک پروژه در مرحله طراحی اخیراً در دسترس نیست. به عنوان یک مشکل، برآورد هزینه در زمان واقعی از تعاملات متوالی انتخاب اجزای ساختمانی چند جایگزین یک تهدید بالقوه برای موفقیت پروژه ها است، مگر اینکه یک سیستم تجسم وجود داشته باشد که به تصمیم گیری در مورد هزینه های اقلام مختلف ساختمان و مناسب بودن اقلام کمک کند. این تحقیق ابزار قدرتمندی است که به صاحب پروژه اجازه می دهد تا با انتخاب بصری مواد مورد علاقه خود در مرحله طراحی، ترتیب تنوع را کاهش دهد. این کاربرد مدل سازی اطلاعات ساختمان (BIM) با واقعیت مجازی (VR) را برای بهبود برآورد هزینه (CE) و فرآیند انتخاب مصالح بیان می کند. محققین از فناوری BIM و واقعیت مجازی برای افزایش تجسم و پردازش برآورد هزینه پروژه در صنعت ساخت و ساز استفاده می کنند. در این مطالعه، هدف اولیه توسعه یک سیستم BIM-VR-CE است که به ذینفعان ساخت و ساز کمک می کند تا هزینه های اقلام مختلف ساختمان و مناسب بودن اقلام را تجسم کنند و به سرعت تصمیم بگیرند. بر این اساس، نویسندگان یک سیستم BIM-VR-CE را توسعه دادند که فناوری BIM و واقعیت مجازی را با استفاده از Unity 3D یکپارچه می کند. پیمایش محیط های ساختمانی به صورت بلادرنگ با قابلیت انتخاب هزینه و موارد مناسب برای عناصر پروژه، اکنون از طریق نمونه اولیه BIM-VR توسعه یافته در این مقاله در دسترس ذینفعان ساخت و ساز است. برای ارزیابی اثربخشی مدل اولیه پیشنهادی، پرسشنامه ای ایجاد شد و ۸۵ ارزیابی جمع آوری شد. یافته های این مقاله پتانسیل قابل توجهی را برای استفاده از مدل پیشنهادی در پروژه های ساختمانی برای مقابله با هزینه، کاهش سفارش های تغییرات و انتخاب عناصر مورد علاقه نشان می دهد.

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