

Developing a BIM-based Visualization and Interactive System for Healthcare Design

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Abstract –

In the building life cycle, the design phase is related to the usability and practicability of the building operation. Communicating ideas regarding the design requirement is the key point. Healthcare building design contains the most rigorous and complex system and should be fully considered. However, designers often only use 2D shop drawings, architectural rendering of viewpoints, and paper models to discuss the design concept and requirements with the stakeholders.

Building Information Modeling (BIM) is a revolutionary technology and solution in the modern architecture, engineering, and construction (AEC) industry. BIM is a suitable information collaboration platform for AEC projects. However, most BIM software still does not provide realistic visualization and simple interactive methods. The stakeholders may not easily imagine and understand the design, then provide feedback in the form of professional medical requirements or advice to designers. To address this problem, this study develops the BIM-based Visualization and Interactive System (BIM-VIS) integrated with BIM, game engine, and virtual reality (VR) technology. The BIM-VIS is a real-time rendering system that shows architecture, the spatial design concept, and building information. Furthermore, users may utilize the wireless gamepad as a controller to easily interact with building objects. Finally, the BIM-VIS system was applied in a selected test to demonstrate the effectiveness of interactive BIM use. Limitations and suggestions are summarized for further applications.

Keywords –

Building Information Modeling (BIM); Virtual Reality (VR); Game Engine; Healthcare Design

1 Introduction

During the building life cycle, there are many different interfaces, types of knowledge, and professionals. Thus, the communication and integration is an important topic for a long period of time. However, the design phase always determines the pattern and practicality of building operation. As medical technology improves everyday, the healthcare design is becoming more complicated. The healthcare design should be fully considered. Thus, suitable design and planning to reduce the healthcare operation costs and improve efficiency, such as medical departments configuration, wayfinding, humanized space design and other important medical factors need to be addressed. Compared to general building designs, the healthcare design is more rigorous and difficult. However, in general healthcare design, designers often only use hundreds of shop drawings, architectural rendering of viewpoints, and paper models to discuss the design concept and requirements with stakeholders, and this usually results in information gaps and misunderstanding. It is difficult for the architect to understand the special requirements and relevance of the medical details. For the medical staff, it is hard to understand the spatial design and to review the design to ensure that it is suitable for medical practice and operations, because they cannot connect and imagine many different medical events with complex shop drawings. Furthermore, the duration of the design and construction are long. After construction, the finished product may be different from the design. This discrepancy is due to the lack of current building design and communication with stakeholders. Therefore, Building Information Modeling (BIM) and Integrated Project Delivery (IPD) concepts should be integrated into healthcare facility design in the early phase. BIM is an emerging technology and solution that is revolutionary in the modern architecture, engineering,

and construction (AEC) industry. BIM includes object-oriented parametric modeling techniques, and it enables the visualization of communicated ideas, analysis, and simulation. It is a suitable information collaboration platform for an AEC project. At present, there are many AEC cases starting to use BIM. However, most BIM software still does not provide realistic visualization and simple interactive methods. Stakeholders, may find it difficult to imagine and understand the design, then provide feedback in the form of professional medical requirements or advice to designers. As mentioned above the blind spot in design phase of building life cycle and deficiencies of BIM. How to provide medical staff or users a realistic visualization and simple interactive communication platform, will be one of the topics in healthcare design.

To address the above problems, this study expects to integrate with BIM and game engine technology to develop a visualization and interactive system of healthcare design. It can improve the visualization performance for BIM, and integrate medical staff experiences, knowledges, and special requirements of this system. It will show the real-time rendering virtual space, information, and other customized functions of the hospital building for healthcare facility design options. Furthermore, the system user may utilize the wireless gamepad as a controller to interact with BIM model in this system. This system will improve the visualization and interactive operations, and it can be an efficient communication and presentation system for integrating opinions with medical staff.

2 Literature Review

Kang et al. (2014) updated their BIM CAVE (Computer Aided Virtual Environment) system based on Autodesk Navisworks to display the BIM 4D construction sequence. The CAVE system included 3 screen walls and 3 computers to project the real-time rendered images of the Autodesk Navisworks model. The BIM CAVE system controls the camera location, aiming angle and field of view (FOV) in Navisworks, so that the 3 screen walls can project the 3D BIM model synchronously. It was designed to facilitate users feeling the sense of presence in a 3D computer model [1].

Kang et al. (2015) presented how the BIM CAVE application has been modified, and updated the BIM CAVE immersive space with 9 screen walls to enhance virtual reality and user experience [2].

Wu and Kaushik (2015) integrated BIM and a game engine to create a system framework for simplified design scenarios for sustainable design that transforms static design models and information into an interactive gaming environment to improve the communication between designers and customers [3].

Hilfert and König (2016) presented a way to build a low cost, highly immersive virtual reality environment for the engineering and construction industries. Using an Oculus Rift headset, Leap Motion hand-tracking device, and Unreal Engine 4 as the game core, they created a virtual scene that shows the interactive in an immersive virtual reality in different scenarios. In the process, BIM data can be imported, and automatic mapping materials in the Unreal Engine 4 with the developed plug-in accelerate and simplify the process [4].

The related topics of integrated BIM, game engine, and VR are reviewed. This study will be considering how to develop and integrate the BIM, game engine, and VR technology with related knowledge into healthcare facility design, and present the hospital scenes with healthcare facility design research and experience in VR space to promote current communication methods in the design phase. Therefore, the stakeholders can understand the detailed results of the healthcare facility designed with VR experience; meanwhile, the stakeholders can provide feedback and advice to designers.

3 System Development

This study develops the BIM-based Visualization and Interactive System (BIM-VIS) integrated with BIM, game engine and VR technologies. The BIM-VIS provides a VR space to improve visual communication between designers and medical staff. In order to provide the VR experience when a user operates the BIM-VIS for browsing the BIM model scene, this study involves building a semi-immersive VR projection system to display the BIM model scenes of the BIM-VIS. The semi-immersive VR system provides a greater appreciation of scale than VR on a Head-mounted Display (HMD). In addition, images can be provided that are of a far greater resolution than HMD and this implementation provides the ability to share the virtual experience [5].

3.1 System Concepts and Framework

BIM-VIS can strengthen visual communication, and improve the visualization and interactive abilities more than existing BIM software. The designer can integrate user experience from medical staff in the design phase to enhance architectural design efficacy and ensure the user requirements are met. BIM-VIS functional concepts as follows:

1. Browsing Experience Module: BIM-VIS integrates existing functions of the game engine for developing the browsing experience module. It provides users with free browsing with a first-

- person view in the virtual building. Users can utilize the wireless gamepad as a controller to easily interact with the building scene. This function can reduce operational technical limitations. Compared to most BIM software that uses a keyboard and mouse, BIM-VIS has an easier and more interactive operation experience for BIM model browsing.
2. Scene Map & Interest Points Navigation Module: BIM-VIS integrates the advantages of 2D shop drawings in a 3D virtual interior space. This function provides user instantly understand the current position and floor of the hospital. In addition, the developer can set interest points in key spaces to provide the user with a quick switch between the interest points on the scene map to move to the key space or to speed up the virtual browsing.
 3. Height Simulation Module: BIM-VIS allows the user to change 3 different roles' height to simulate the space collision, and review the friendly design space.
 4. Path Track Record Module: BIM-VIS provides a path track record function for statistics on the user's movement distance, path selection, speed, and time. However, the designer or related healthcare facility design research team can use statistics to review the hospital symbols' setup position, height, angles, quantity, and design.
 5. Healthcare Design Research and Knowledge Tips Module: BIM-VIS integrates related healthcare facility design research and knowledge for design reference. When the user is near and focuses on an issue bubble in the scene, the BIM-VIS accesses the server database to get corresponding design research and information, then shows the content on the information card. It can help the stakeholders understand the healthcare facility design research and knowledge on a specific space or piece of equipment.

After, development the BIM-VIS will be consistent with the patient medical scenario. A BIM-VIS user can use system functions and browse the medical building space for review, and discuss the healthcare facility design in a virtual environment. This study can be used as knowledge accumulation and a reference for any next healthcare facility design project.

In this study, the BIM-VIS was developed by BIM and a game engine. The game engine selects the Unreal Engine 4 (UE4) which was developed by Epic Games, Inc. The main reason is UE4 is open source and free, along with all future updates. In addition, UE4 can support a huge and complex model while still operating smoothly. However, the developer can use the UE4 "Blueprint" visual scripting system to customize

function modules and user interfaces. The blueprint is a complete gameplay scripting system based on the concept of using a node-based interface to create gameplay elements. It is used to define object-oriented classes or object in UE4 [6]. Overall, the visualization and interactive development system of UE4 meets the requirements of the game engine.

The BIM-VIS has three operation process (see Figure 1), including "BIM Model Operation Process," "Game Engine Operation Process," and "Presentation & Communication Process," as follows:

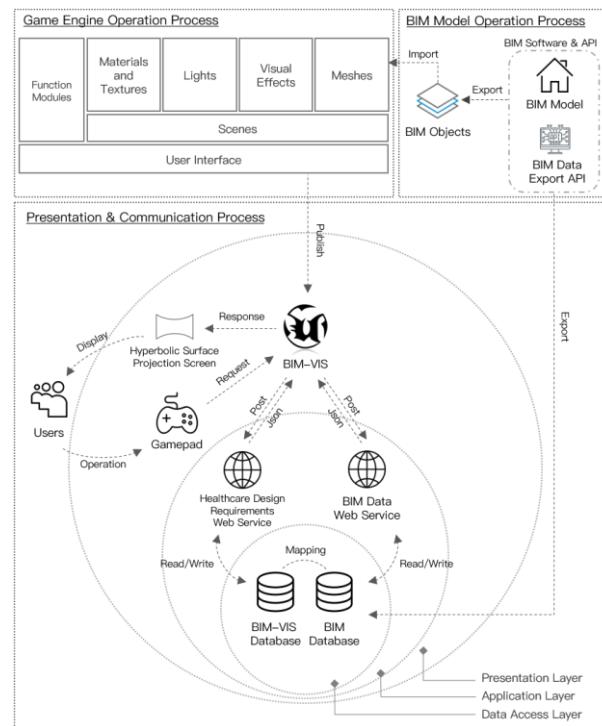


Figure 1. The system framework of BIM-VIS

1. BIM Model Operation Process

The purpose is to export and upload the BIM model data from Revit to the BIM database via the BIM data export API (Application Programming Interface).

The BIM model is exported to the .fbx file format, which only maintained the model element, ID, name, and position data. Therefore, in this process, the BIM database is purpose to access non-geometric information such as BIM model element ID, size, material, manufacture, etc. The BIM-VIS can access the BIM information in BIM database, by BIM model element ID. In addition, the complete BIM central model need to process the unit conversion, reduce the polygon faces, and unwrap the model texture UVW in Autodesk 3ds Max. Then export the BIM model (.fbx file) for import to the UE4.

2. Game Engine Operation Process

The game engine provides a variety of tools and compute technologies for development the huge and complex game scene with interactive functions and user interfaces. Therefore, it can improve the operation smoothness and efficiency of the BIM model, and using lightings, materials, visual effects, and camera settings of game engine enhances visualization of the BIM model. The purpose of this process is development of system function modules, user interfaces, and building of the healthcare facility interior scenes in UE4. In addition, the BIM-VIS can access non-geometric information of BIM model elements in the BIM database, and medical research and requirements in BIM-VIS database via customize system function modules. It can also build and customize function modules like the “Path Track Record Module” and the “Height Simulation Module” of the BIM-VIS.

3. Presentation & Communication Process

This process is a three-tier framework, including the “Data Access Layer”, “Application Layer”, and “Presentation Layer”, as follows:

- **Data Access Layer**

This layer contains the BIM-VIS database with the hospital design requirements and research information. The BIM database stores the non-geometric information of BIM model elements.

- **Application Layer**

This layer contains the “Hospital Design Requirements Web Service” and the “BIM Data Web Service” as a connection link with Data Access Layer and Presentation Layer. BIM-VIS uses JSON (JavaScript Object Notation) as a data exchange language.

When the web service receives a request from BIM-VIS, the web service converts the model ID to JSON, then posts to the server to read and write the information (such as healthcare facility design requirements and medical research) from the BIM-VIS database, or the BIM data (such as BIM model element material, size, etc.) from the BIM database, and then converts the information via the web service, and responds to the BIM-VIS.

- **Presentation Layer**

This layer contains the BIM-VIS, a hyperbolic surface projection screen, and a wireless gamepad. In “Game Engine Operation Process,” the UE4 develops the virtual hospital scenes, then packages and publishes them to the BIM-VIS. The BIM-VIS is the main execution and display platform. The BIM-VIS projects the virtual hospital scenes and contents to the hyperbolic

surface projection screen, and users can utilize the wireless gamepad as controller for the BIM-VIS.

Regarding hardware, in order to provide the VR experience when a user operates the BIM-VIS for browsing the BIM model scene, this study involves building a semi-immersive VR space. The research team set up a workstation computer with 2 Nvidia Quadro K2000 graphics cards to execute the BIM-VIS, a Microsoft Xbox One wireless gamepad for controller, a 4992×1994 cm hyperbolic surface projection screen made by wood with projector screen paint, and 6 projectors combined to provide 5K high-definition resolution (see Figure 2).

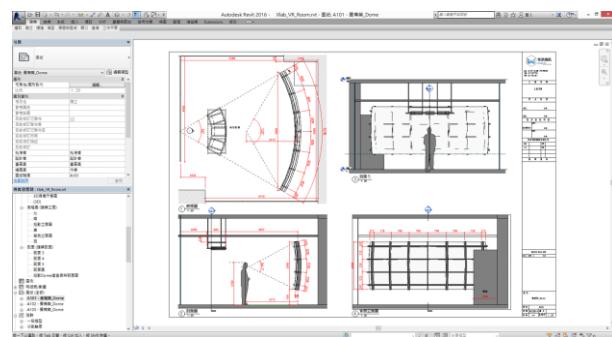


Figure 2. The shop drawing of a hyperbolic surface projection screen

3.2 System Workflow

The following describes the system workflow of BIM-VIS (see Figure 3). The BIM-VIS has three operation workflows, including “BIM Model Operation Workflow,” “BIM Model Post-Process Workflow,” and “Game Engine Operation Workflow,” as follows:

3.2.1 BIM Model Operation Workflow

1. Development of the BIM model in Autodesk Revit.
2. Export and upload the BIM model data, such as model ID, size, material, etc. from Revit to the BIM database via BIM data export API.
3. In order to provide the readable model for 3ds Max in “BIM Model Post-Process Workflow”, export the BIM model (.fbx format) in Revit.

3.2.2 BIM Model Post-Process Workflow

The purpose is convert the BIM model unit, breakdown complex model, simplify the polygon faces, and unwrap the model texture in 3ds Max.

1. Since the UE4 world unit is centimeter (cm), however, Revit unit is millimeter (mm). In order to ensure the model scale is correct, this study is convert the BIM model unit to cm in 3ds Max.
2. Import the BIM central model (.fbx) to 3ds Max.
3. Finding the complex BIM model element, such as

- medical equipment, etc. It needs to manually determine whether the complex BIM model element, then isolate an BIM model element.
4. Since high polygon faces numbers may cause low performance and computer resource overload in UE4, thus, breakdown the isolated BIM element, and simplify the polygon faces using 3ds Max function. When polygon faces simplified, end isolate and back to BIM central model status.
 5. For avoid lightmap overlap, it needs to generate a new model texture UV channel, and unwrap the model texture UVW. However, this study using third-party script of 3ds Max: "SteamRoller" [7]. The SteamRoller can automatically repeat the process for unwrap model texture UVW.
 6. Export the BIM model (.fbx) in 3ds Max.
 7. In order to provide the readable model for UE4 in "Game Engine Operation Workflow", export the BIM model (.fbx) in 3ds Max.

3.2.3 Game Engine Operation Workflow

The purpose is import the BIM model which finish the post-process in 3ds Max, then build the whole scene of hospital with detail lights, materials, meshes, visual effects settings for simulate the interior scene. In addition, the developer can compile and apply system functions or user interfaces using UE4 Blueprint.

1. Import the BIM model (.fbx) to UE4 scene.
 2. Since the BIM model elements (also known as "Mesh" in UE4) only maintains the model element, ID, name and position data in .fbx model, therefore, align meshes to origin (0,0,0) of UE4 scene to ensure BIM model elements are correct position in UE4 project.
 3. According to the space, function, and requirement for create multiple streaming sublevels in a persistent level, then assign meshes to multiple sublevels. The purpose avoids too large of the meshes number in a single level, it may cause level read time is too long. In addition, the function module can control the level visibility, it can be used for changing different scene, such as turn on/off the "Chemotherapy area" level.
 4. Execution of UE4 world settings, project settings, and edit contents of UE4 scene, including lights, textures, material, meshes, levels, visual effects settings, etc. for improve the visualization.
- World Settings: The world settings including the detail setting of physics, lightmass calculation, game mode, etc.
 - Project Settings: For detail settings of current UE4 project, including project name, project initial level, operation settings, etc.

- Materials & Textures Settings: Including material and texture settings such as material roughness, reflectivity, etc.
- Lightings Settings: Including detail settings like intensity, temperature, light source radius, mobility of multiple lighting type, such as directional light, spotlight, point light.
- Meshes Settings: Including meshes detail settings, such as mobility, materials, physics, collision, light map resolution, etc.
- Visual Effect Settings: Including post-process detail settings of UE4 scene, such as atmospheric fog, sphere reflection capture, etc.
- 5. Finished the hospital scene and detail settings. This study compiles system function modules and user interfaces using Blueprint for communication between server and client, and achieve system functions.
- 6. Build the UE4 project. UE4 start to compute and render all the levels in the scenes, including meshes, lightings, materials, and other detail settings. When build successful, UE4 updates the scenes and presents the results in UE4.
- 7. Complete the build, the developer should execute the UE4 project. If the results are not reach expectation, the developer should be re-setting, and test the UE4 project again, until it reaches the expectation quality.
- 8. When UE4 project reach the quality of the expected results, then package the project to executable file, also known as BIM-VIS main executable file in this study. The purpose provides the user can execute the BIM-VIS, but not on UE4 editor.

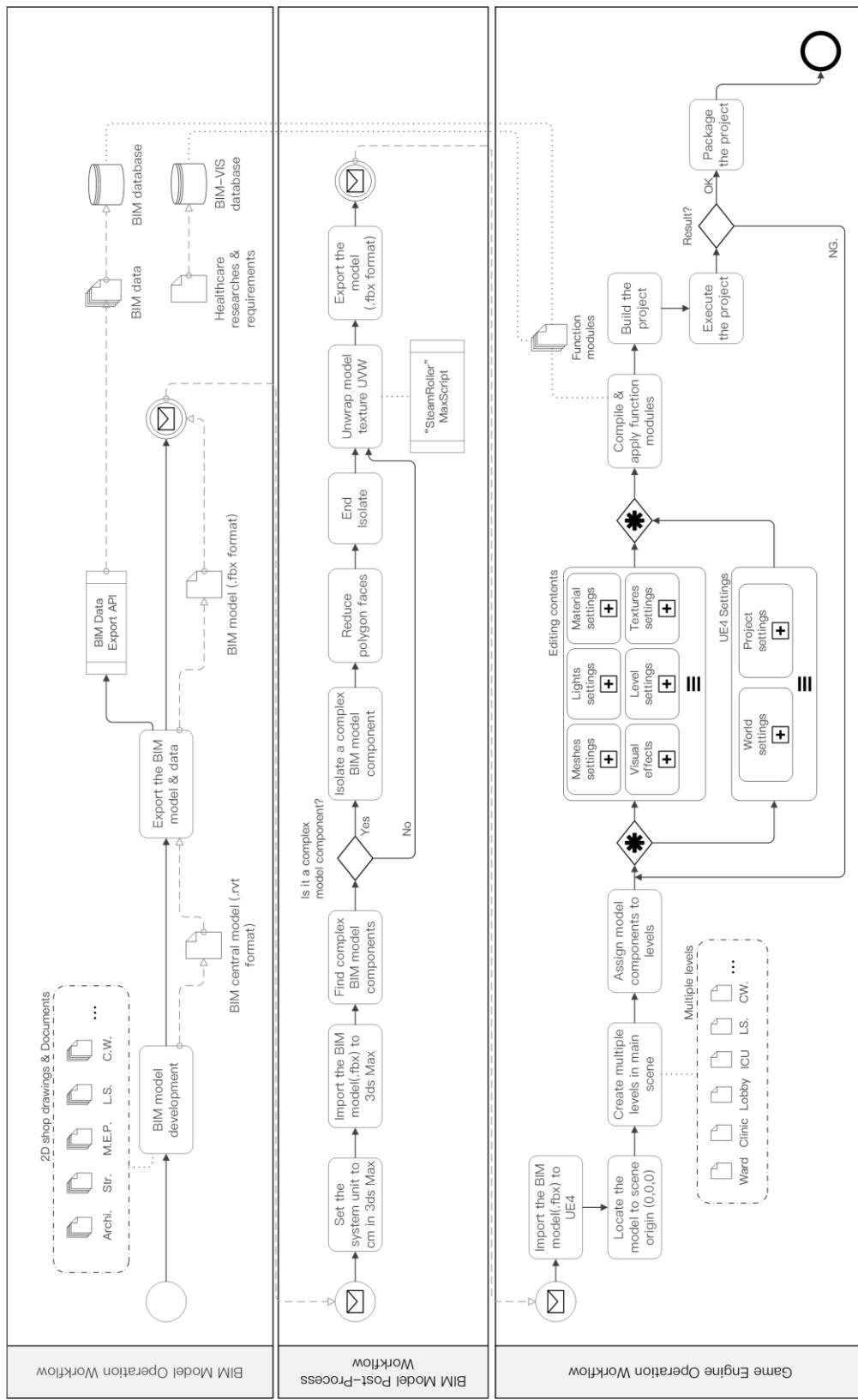


Figure 3. The system workflow of BIM-VIS

4 Pilot Case and Discussions

The pilot test is design phase of National Taiwan University Cancer Center (NTUCC) building. NTUCC is a cancer specialist hospital and research center. NTUCC is donated to National Taiwan University by YongLin Healthcare Foundation. The building located in Taipei City, cover an area of 3.1 hectares, 14 floors on the ground and 4 floors underground.

At the beginning of the design phase, designers and medical staff (such as doctors, nurses) were use 2D shop drawings, architectural renderings and paper models to discuss the healthcare design and medical professional requirements. However, medical staff cannot too easy imagine, and understand the hospital space design from hundreds of shop drawings, renderings, and paper models, then provide in the form of professional medical requirements, experience to designers. They had information gaps and misunderstanding between designers and medical staff. In addition, designers and medical staff were start to use BIM solution into the design phase of NTUCC to improve above problems. Thus, the design team created BIM model of NTUCC by Revit (see Figure 4), then project stakeholders can review the BIM model, and discuss the healthcare design in BIM software.

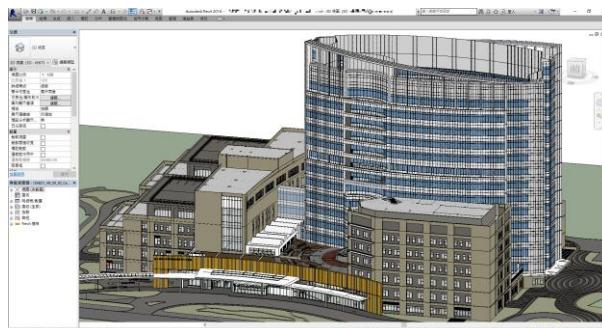


Figure 4. NTUCC BIM central model in Revit

However, most BIM software still does not provide realistic visualization and simple interactive methods. The stakeholders may not easily imagine and understand the lightings, materials, medical spaces design. In this case, the purpose of development and application the BIM-VIS is used to assist medical staff and other stakeholders to understand the complicated and precise architectural design, and simulate lightings, shadows, materials, spaces, height design, path track, etc. of NTUCC in a virtual environment. Therefore, designers and medical staff can collect feedback, and discuss the design requirements, ideas, or problems on this visualization and interactive platform.

The BIM-VIS achieved the following features in this pilot test, as follows:

- Browsing Experience (see Figure 5)



Figure 5. A medical doctor is browsing the virtual NTUCC building in design phase

- Scene Map & Interest Points Navigation (see Figure 6)



Figure 6. 1-floor scene map with interest points

- Height Simulation (see Figure 7)

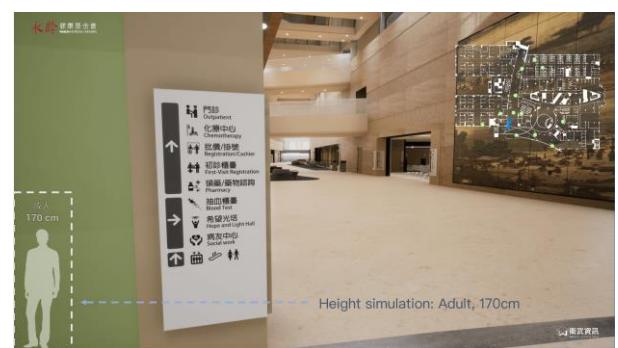


Figure 7. The height simulation status icon

- Path Track Record (see Figure 8)



Figure 8. The path track record map

- Healthcare Design Research and Knowledge Tips (see Figure 9, 10)



Figure 9. An issue bubble in NTUCC clinic area

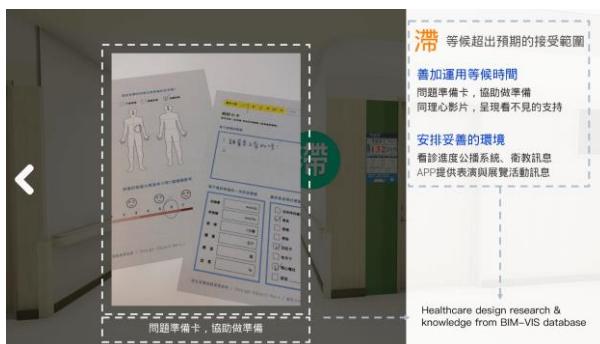


Figure 10. The healthcare design research and knowledge on an information card in NTUCC clinic area

5 Conclusion

In order to improve the visualization and interactive performance of the BIM, and reduce the communication gap between stakeholders in healthcare facility design. This study develops the BIM-based Visualization and

Interactive System (BIM-VIS) integrated with BIM, game engine, and VR technologies with professional requirements and knowledge for healthcare facility design. The BIM-VIS is a real-time rendering system that shows real-time rendering architecture, the spatial design concept, and other customized system functions for healthcare design. User can utilize the wireless gamepad as controller to interact with BIM model and information in BIM-VIS. Meanwhile, in order to provide the VR experience when a user operates the BIM-VIS, this study creates a semi-immersive VR space. The research team set up a workstation computer to execute the BIM-VIS, a wireless gamepad for controller, a hyperbolic surface projection screen by wood with projector screen paint, and 6 projectors combined to provide 5K high-definition resolution.

Based on the system result of pilot test, it verified that functions of the BIM-VIS were useful. Furthermore, some factors, such as hardware cost may cause the stakeholders to hesitate for adopting this system. However, the future research may focus on speed up the workflow, compile functions or scripts for automatic execute works.

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