REAL-TIME VISUALIZATION IN THE DESIGN CONTEXT

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Abstract

Having been a promising visualization tool since 1950s, ironically, virtual reality is not widely used in the architectural design and evaluation process due to several constrains, such as the high cost of equipments and advanced programming skills required. This paper described the collaboration between design computing courses and architecture design studios that have been taught at Savannah College of Art and Design (SCAD) in 2004 and 2005. These courses explored several practical methods to integrate Low Cost Virtual Reality Aided Design (LC-VRAD) in the architectural design process. As a summary of the collaboration, this paper refers to three main aspects: (1) How to use game engine to design an affordable VR system in the ordinary studio environment. (2) How to integrate VR, into the design process, not only as a visualization tool, but also as a design instrument. (3) How to evaluate different methods of representing architectural models based on the efficiency of workflow, rendering quality and users' feedback.

Support by the Game and Interactive Design Department at SCAD, students in the School of Building Arts implemented two Low Cost VRAD methods in various design phases, starting from site analysis, schematic design, design development to the final presentation. Two popular game engines, Epic Game's Unreal engine and Director MX's Shockwave engine, were introduced to students to visualize their project in real -time. We discussed computer-aided design theories including the application of VR, as well as digital computing and human computer interaction. At the end of each quarter, feedbacks from students and faculties were collected and analyzed. These methods were revised and improved consistently across 2004 and 2005 academic year.

Keywords: *Virtual Reality, Real-Time Visualization, Game Engine .*

INTRODUCTION: PEDAGOGICAL OBJECTIVES

As visualization and communication tools, computer renderings and fly through animations are widely used by students in the Architecture Department at Savannah College of Art and Design (SCAD). However, we find these digital tools are only used for producing the final presentation at the end of the design stage rather than being integrated into the design process at the early beginning. Many students stick with the conventional design methods by using hand drawings and physical models in the schematic design, and only use computer to generate presentation boards after the design is completed. This workflow currently widely used in the architecture design studio does not provide an efficient way to study, experience, and evaluate the design within the digital environment.

Another constrain we find in the studio is the disconnection between good-looking computer-generated (CG) renderings and the actual design quality. Although with the fast growing digital technology, CG renderings are getting more and more photorealistic, neither still-renderings nor animations can provide an interactive approach to visualize the design. The viewer's path and viewpoints are not self-chosen but pre-defined. Therefore, an important feature of spatial experiencing in the real world is missing in these visualization tools ---the interaction between viewers and the environment. Students usually spend a significant amount of time to render an animation. However, a pre-defined camera path fails to provide the freedom to interact with the design during the review. As the result, students are discouraged to spend time to create animations.

To overcome these constrains, we have explored the real-time rendering techniques and several virtual reality[1] applications, which provide students and faculties an instant 3D visualization and inter-

[1] Virtual Reality (VR) opened a new field for architecture design. The key point is the user's autonomy of movement within the virtual space (Conway Lloyd Morgan, Giuiano Zampi. 1995). With real time technology, viewers could navigate a 3D environment with external devices (joystick, mouse, keyboard or motion tracking system). The display devices such as head mount display (HMD), stereo panorama screen, and CAVE system create a fully immersive virtual environment. Also, latest web based 3D technology turned Internet into a powerful media for VR. Based on the devices and presence level, VR could be classified as "immersive VR" and "desktop VR" (John Vince. 2004).

action platform for design communication. We hope this platform could mimic the way people see and experience reality, to simulate "the viewer's ability to control his or her own actions-especially to look around and see the environment at will." (Yehuda E. Kalay. 2004). More important, we hope to find a new virtual reality aided design (VRAD[2]) method and integrate this method in the architecture design studio across all design phases.

GAME ENGINE AND LOW COST VRAD

Typical immersive VRAD systems such as HMD and motion tracking system are very expensive and require a large space to set up. They are not practical for the studio environment. Another constrain of conventional VRAD comes from its complex computer programming language. It requires designers to have advanced programming skills, and therefore restricts its application in the field of architectural design.

Compared with the high-end VR lab's equipment, we find game engine is more affordable for most general founded researchers and architecture institutes. The game industry is one of the quickest growing technology-intense industries in the last decade. The latest development of computer graphic card and the rendering technology is pushing game engines into a new level. Today, game engines are using bump map, normal map, HDRI rendering, dynamic lighting, and are capable of handling very complex, high-polygon geometries with a high frame rate. Different from the early age game model, high quality and photorealistic real-time renderings "truly blur the line between pre-rendered computer-generated film imagery and real-time rendered 3D game imagery." (Karen Moltenbrey. 2003) The most sophisticated rendering pipelines are now found not on specialized scientific machines, but on PC video cards costing less than $500. The most sophisticated and responsive interactive simulations are now found in the engines build to power games. (Michael Lewis and Jeffrey Jacobson. 2002).

Besides the low price and the ability of generating high quality renderings, another benefit of using game engine is its short learning curve. As a new generation growing up with internet and video games, most students are very familiar with the computer games and feel comfortable to navigate in the virtual environment with the keyboard and joystick. The learning curve of manipulating these game engines is very short. In 2003, we started to look for game engines and third party plug-ins capable of importing CAD models from conventional architecture design software. With the support from the Interactive and Game Design Department at SCAD, we finally selected two popular game engines. One is Epic Game's Unreal engine[3]; while the other is MacroMedia's Director MX[4] with its shockwave 3D engine. With these game engines, we designed a Low Cost Virtual Reality (LC-VR) system using a desktop, a big screen and a mouse /joystick. (Figure 1) The cost was only around $ 2,500. Compared with the expensive "immersive VR" devices such as stereoscopic display and panorama screen, this LC-VR system perfectly met our budgets.

In 2003, a joint project named "Virtual Ronchamp Church" was launched by us and the Game Design Department to test the ability of Unreal game engine. We modeled Le Corbsier's Nortdam church in CAD program and transferred it into Unreal. (Figure 2) During the ten weeks in working on this project, Unreal engine demonstrated a great power to handle complex 3D forms (such as the high-polygon curved roof), high-resolution textures (1024 pixel by 1024 pixel), and pho-

Fig 1. Devices for Desktop VR: Screen, projector, Desktop, keyboard, mouse, and joystick.

[2] VR Aided Design (VRAD), as "computer-aided design using the methods of virtual reality" (Holger Regenbrecht, Dirk Donath 1997), allows architects while being immersed into a virtual space.

[3] Epic Games' Unreal Tournament (UT) game engine is famous for its fast rendering speed, and well-designed level editing tools. UT is the most "modified" game title with over 25,000 people building their own versions of the various games in the series (Lisa Taylor, 2003). Due to its excellent rendering quality, it is even used for quick preview film scene. (http://www.machinima.org)

[4] Macromedia's Director MX is a popular multimedia-authoring tool. Compared with other web 3D tools such as Adobe Atmosphere and Active Worlds, Director MX has a larger user community and is better integrated with 3D modeling programs.

Fig 2. Screen capture from real time walk through of virtual Roncham Church in Unreal.

torealistic lighting effects. We were satisfied with the high frame rate the Unreal engine achieved with a promising rendering quality in real-time.

Meanwhile, we tested Shockwave game engine form Director MX as an alternative solution of Unreal engine. Although Director's rendering style was not as photorealistic as Unreal, it enabled us to composite text, image, video, audio, and interactive 3D model into a single interface. It also supported web publication, which would make the communication between students, faculties and clients more flexible. In 2003, an experimental project named " HomeNet Too" was developed by the author with M.I.N.D lab in Michigan Sate University. A large 3D environment was successfully published into a web format after ten weeks' development. (Figure 3)

TEACHING METHODS AND STUDENT PROJECTS

After these two experiments, we started to teach with new methods in the Architecture Department at SCAD. Two game engines were introduced to students in the spatial simulation and visualization courses in 2004 and 2005. Students were asked to bring their ongoing studio projects into these courses and use game engines to facilitate the design process.

Method 1: Unreal game engine

In this method, students from two courses worked together as a team. One course was the 3rd year Architecture Design Studio, focusing on site planning. The other course was Spatial Simulation and Visualization, which concentrated on the application of real-time rendering and visualization. Each student from Architecture Design Studio was assigned a co-worker from the Spatial Simulation and Visualization course to form a team. These two courses started simultaneously at the beginning of the quarter and worked parallel to feed each other in the subsequent ten weeks. Digital presentations supported by Unreal game engine were set up regularly and served as milestones to evaluate the design. (Figure 4)

Site Analysis and Schematic Design

To counteract the habit of using computer solely as a final presentation tool, we introduced VR environment into the early stage of the design - site analysis and schematic design. A computer-generated virtual site including accurate terrain, land-

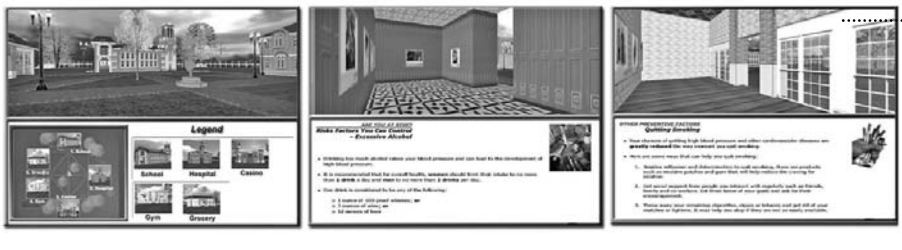

Fig 3. Screen capture: 3D interface of HomeNetToo project

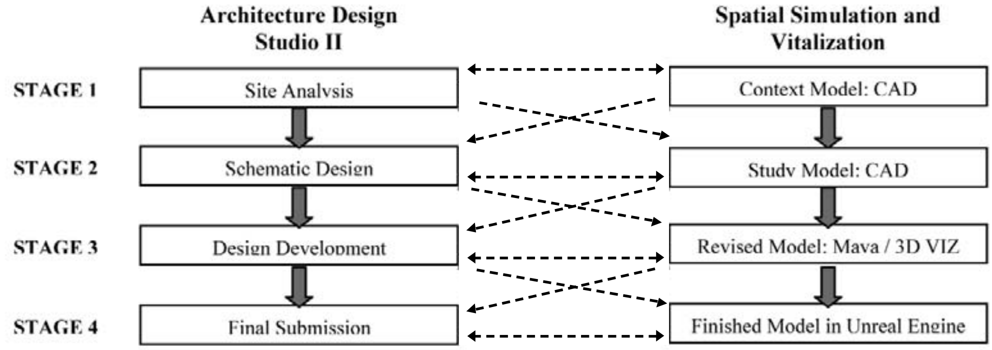

Fig 4. Diagram: interactions of studio course and electronic design course.

scape, and existing buildings, was provided to students at the beginning of the quarter. By using the game engine, environment fog, animated cloud, massive trees, and plants were carefully added to match the characteristics of the actual site. After a short period of training, students quickly grasped the technique in navigating the virtual site. Through a virtual "site tour", students dynamically experienced the environment by "walking" with their mouse and keyboard. They "stepped" on the roof of an existing building and overviewed the entire virtual site. They "flied" through the site by using "none gravity" mode and "took pictures" by capturing the snapshot and saving images for future reference. (Figure 5) By "walking through" the site, design issues related to potential building form, materials, and the relationship between new building and the existing context were discussed.

Design Development

To reduce the required programming skill and maximize the efficiency of workflow, we used Alias Maya to transfer CAD models to Unreal engine. This simple pipeline allowed students to import detailed 3D models from Micro station, Revit or AutoCAD into the real-time rendering. Textures were made in Adobe Photoshop and mapped onto the 3D geometry in Maya. Within the Unreal Level Editor, sun light and sky light were set up to generate shadow maps. Point lights and spot lights were reserved to correcting subtle lighting problems. Environment cube map was used to simulate highly reflective metal surface in real-time. In this design stage, team members from both courses were required to meet frequently to evaluate the design in the Unreal simulated environment. The following design issues were addressed among team members during the real-time walk through.

- The external circulation of the site
- The internal circulation of the building
- The visual connection between the designed building and existing context.
- The view along the proposed pedestrian path

Final Presentation

A LC-VR system was used during the final review of the 3rd year Architecture Design Studio[5]. Faculty juries sitting in front of a projected screen could observe a student operator walking inside and outside of the virtual building. The operator could also follow commands from jury members, such as "turn around", "go to the second floor", "look outside

Fig 5. Students are doing virtual site survey in Lab.

[5] The critique of 3rd year Architecture Design Studio focused on two issues. First, it was whether the design was well integrated with the existing context and connected with other parts of the site. The second issue was "the sense of a place", which shows its clear perceptual identity: be recognizable, memorable, vivid, engaging of viewers attention (Kevin Lynch, Gray Hack. 1984). Psychological and esthetics issues such as space flow, materials, proportion were also discussed during the critique.

Fig 6. Desktop VR and presentation boards were used simultaneously in the final presentation.

from the window", and etc. (Figure 6)

Some faculties actually changed their role from a passive audience to an active operator. By using the keyboard or joystick, they selected his/her own path, "walked" into the building, asked questions as well as gave comments simultaneously. It was very similar as the natural way of critiquing a building when people are physically experiencing it. From the projected screen, all viewers directly observed the operator's navigation behavior. Viewers knew which part of the lobby attracted the operator's attention, how long it took the operator to find the stairs to go upstairs, where the operator got confused and even lost his/her orientation. (Figure 7)

We did a follow-up questionnaire right after the final review. The feedbacks from colleagues, students and clients were very positive. As a conclusion, several successful aspects of this method are:

- The pipeline from CAD to real-time engine is very easy to use.
- It does not require any programming skills.
- A CAD model can be imported into VR in several minutes.
- Students do not need to spend hours to create presentation boards.

Faculties were very excited to see that LC-VR system became a new design instrument[6] to evaluate the spatial quality of a design project. Complex spatial arrangements and features of the design were recognized at the moment of "walking" inside of the building.

Method 2: Director MX's Shockwave game engine

After the success of the first method with Unreal, we started the second method in the following quarter. Macromedia's Director MX was used as an interactive presentation tool. Different from photo realistic renderings of Unreal, Director MX features abstract rendering style and rich multimedia components. Students were taught how to create a web interface to visualize their designs within an interactive 3D environment. By using Director's script library[7], various components such as text, 2D image, 3D model, flash animation, video, and audio were combined together to present a design

Fig 7. Screen capture of virtual walk through in Unreal engine.

[6] "The model becomes a design instrument, since most of the qualities of the design can be evaluated in the model." (Gerhard Schmitt.1999)
[7] Director MX's script library allows students to integrate 3D forms with various interactions and media easily. Finally, text, image, animation, 3D form, audio, and video were assembled together within a single interface.

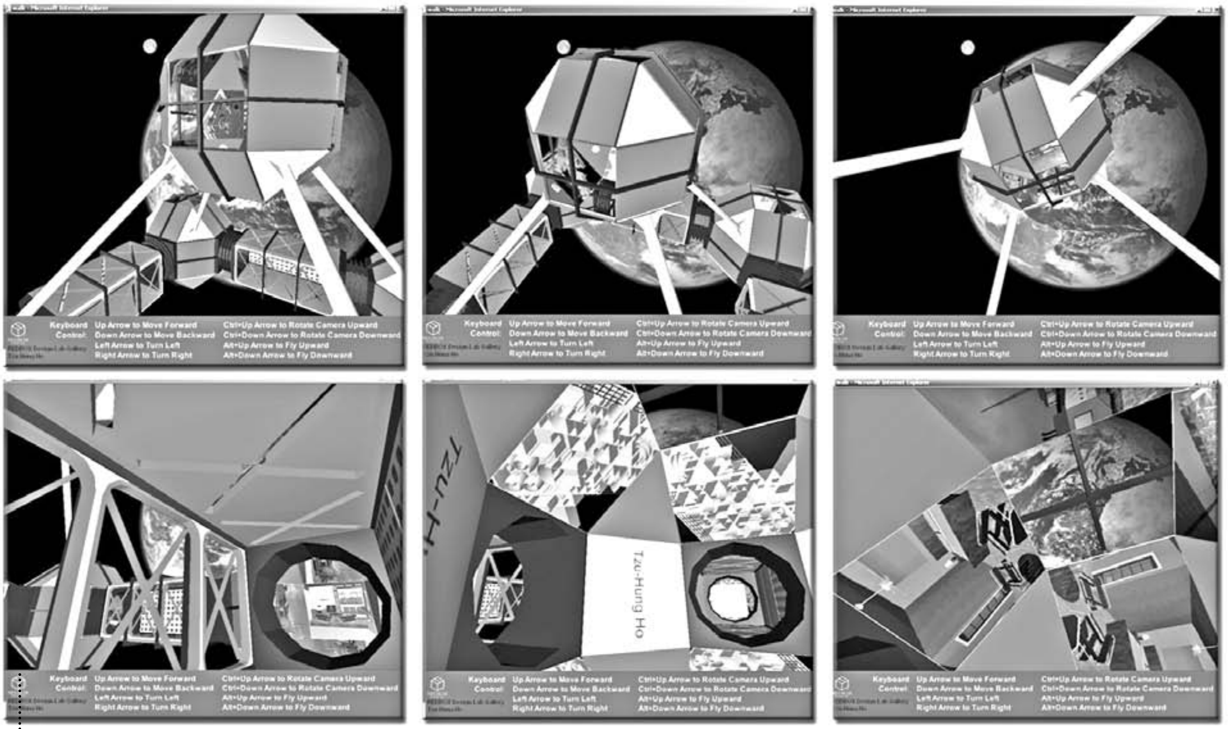

Fig 8. Animated texture as building skin in Director MX engine.

scheme on the web. To reduce the learning curve, several components[8] were developed by the author using Director's Lingo language and given to students at the beginning of the quarter.

In ten weeks, students used typical CAD modeling tools to complete their detailed models and then imported them into Director MX's engine. They published their studio projects to a 3D online environment. They designed various real-time interactions, which allowed users to walk inside of a virtual room, switch materials, rotate models and change camera angles. (Figure 8) At the end of the quarter, students uploaded their virtual environments online and collected feedback from studio advisors and other students.

Compared with Unreal, Director provides customized user interfaces and web-based presentations. It gives students a longer period of time to collect feedback from a large user group.

However, based on the survey data collected from students, the second method received a lower satisfaction rate. We believe there are two primary reasons. The first reason is the rendering quality. Unreal game engine and Director MX engine provide totally different rendering styles. VR running with Unreal can be described as "hyper reality[9]" due to its photorealistic rendering. (Figure 9) On the other hand, VR running with Director MX's shock-

Fig 9. "Hyper reality" rendering style in Unreal engine.

[8] These script enabled students to navigate 3D world with keyboard; use bitmaps, flash movies and other video files as textures in the real time rendering.

[9] By mimicking the physical world in every detail (Yehuda E. Kalay. 2004), the advantages of "hyper reality" derive from the richness of experience, familiarity, and visual comfort they convey.

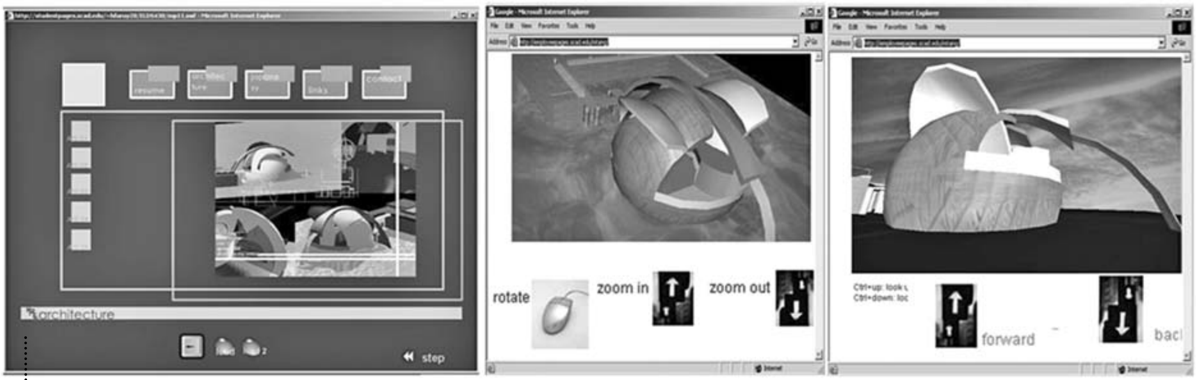

Fig 10. "Abstract reality" rendering style in Director MX.

wave engine is "abstract reality" due to its flat color and none-shadow rendering style. (Figure 10) Obviously, students preferred the photorealistic rendering than abstract rendering style.

The second reason is the interaction. Unreal engine allows viewers to interact with 3D objects in real-time. For example, users can open or close doors and windows, turn on or off lights, and even take an elevator by triggering events. (Figure 11) These interactions increase viewer's presence level psychologically and make the scene more believable. Subsequently, students feel more "involved" in the Unreal's "hyper reality" world than Director's "abstract reality" world.

Other factors affecting students' rate might be the users' presence level. Unreal's interface is a full 3D view, while Director MX is a hybrid interface with 3D windows embedded with 2D panels and buttons. (Figure 12)

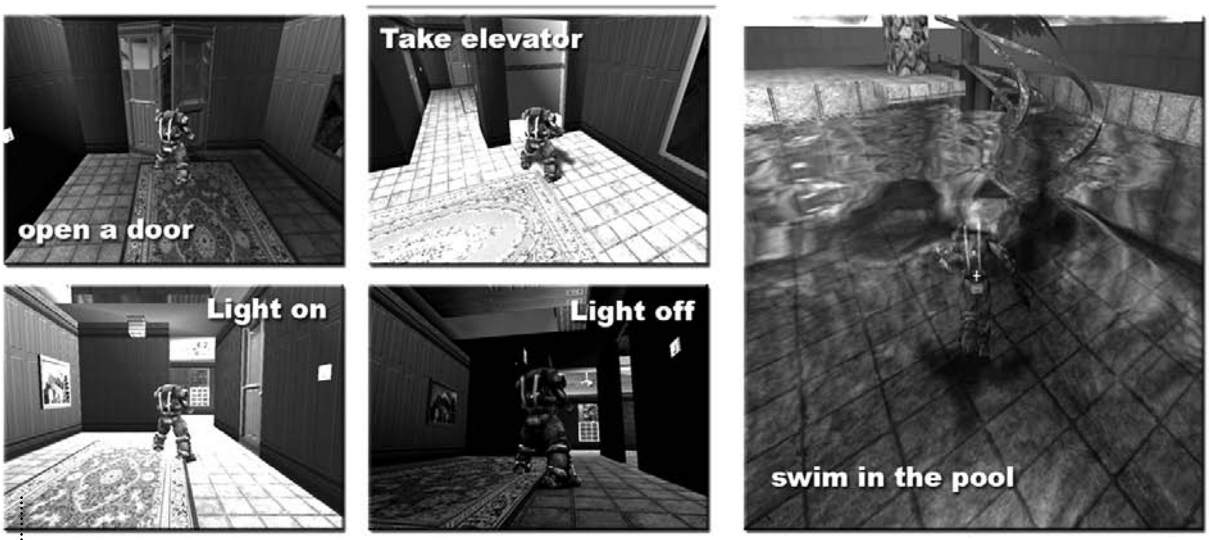

Fig 11. Real time interactions in Unreal engine.

Fig 12. Hybrid interface in Director MX.

Fig 13.
Students are doing presentations with desktop VR to |faculties and clients.

CONCLUSION

During the past three years, our work has been focused on applying LC-VR system in the early architectural design phase, where computer models confront with complex design situations. VRAD integrates site survey, design evaluation, and construction within a single digital environment, which allows a design scheme to be generated, visualized and published online quickly. In general, these two experimental methods have achieved this primary goal by introducing interactive game engines to students. The average time for a student to finish a real-time rendering project is ten weeks, including five weeks of training[10] and five weeks of working time. With a short learning curve, students can learn the real-time rendering technique fast and use it simultaneously with their design studio projects.

By implementing these two methods to the studio projects, we find some benefits as well as some constraints.

Benefit of VRAD

There is a significant amount of positive feedbacks from faculties and students in the 3rd year Architecture Design Studio. Some students commented that they learned a lot about the spatial quality when they "interactively walked inside" of the space they designed. After exploring VR environment, students had a better understanding of the meaning of "movement patterns and behavior circuits" (Kevin Lynch, Gray Hack. 1984). After observing human & environment interactions by VRAD, some students even took their projects further by independent research, which was beyond the studio's requirements. They analyzed how the color, lighting, and material could affect people's behavior in the space they designed. In the interactive environment of game engine, many design issues such as scale, proportion, rhythm, and circulation are discussed in a more "natural" way when both the professor and the student "walk" into the space simultaneously. (Figure 13) In addition, this interactive presentation has stimulated more arguments and thoughts about spatial recognition, spatial memory and other unforeseeable design issues, which are not addressed by conventional design process.

As a substitution of pre-rendered animation, which is usually the final step of a conventional design process, VRAD, as a design instrument, starts in the very early stage of the design. 3D model can be easily imported into game engine and rendered in real-time. These methods enable students and faculties to design, modify and explore the virtual space and interact with it. After each milestone evaluation in the studio, it is very easy for students to revise their design, update new models and request a second turn evaluation. (Figure 14) It becomes a cycle of refining and evaluation. It makes "design development through comments" possible (Thomas Jung, Ellen Yi-Luen Do. 2000).

Similar as a Mass Multi-player online Game (MMOG)[11], VRAD also extends the conventional studio into an unlimited digital space. It enhances the communication between faculties and students outside of the classroom. The web-based critique can flow consistently through the entire quarter among a large group of students and faculties. The equipment of VRAD, which includes a desktop, specified display and navigation devices, can also be installed in the studio environment. Compared with a web-based virtual world, the local VR system is easier to be used for some specific studio activi-

[10] There are many online tutorials available in the Unreal Website (http://udn.epicgames.com) to allow students to go start the training independelly.
[11] With the blooming of Mass Multi-player online Game (MMOG), "video game space changed from privet to public". (Alberto Iacovoni. 2004). Many online 3D worlds provide players the modeling tools they can build their own houses, decorate their own virtual rooms, and share with other players through the web.

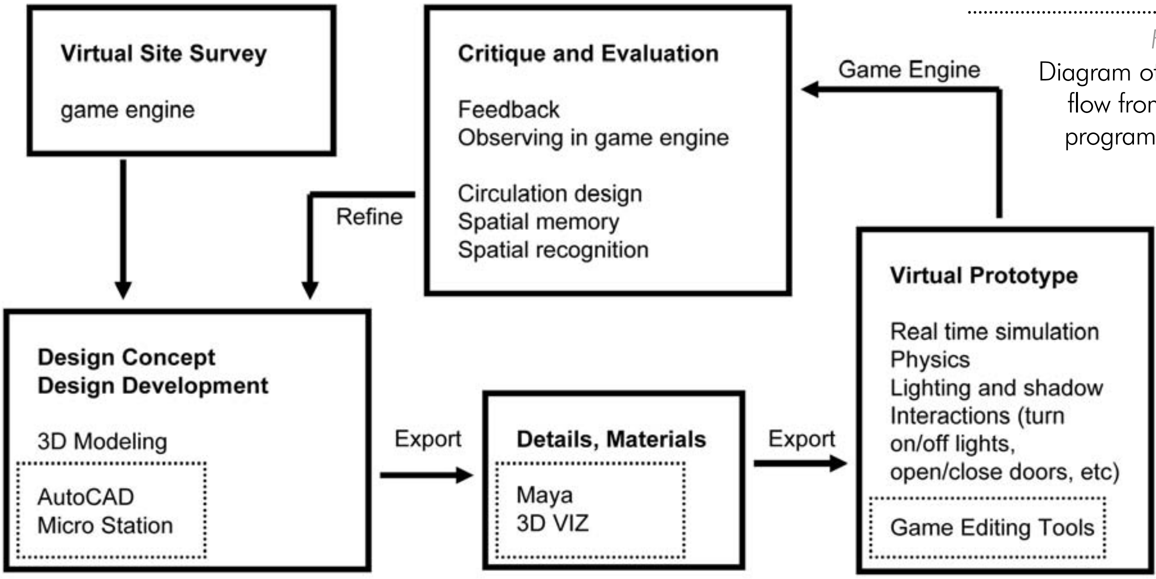

Fig 14. Diagram of work-flow from CAD program to VR.

ties such as lectures and presentations.

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Constrains of VRAD

Although both methods have received positive feedbacks from students and faculties, there are still some technical constrains. We find the performance and frame rate of both game engines will drop down dramatically if a CAD model has a large number of geometries. This constrain requires the entire CAD model to be built up efficiently and carefully in order to minimize the polygon number as much as possible. For students, how to optimize a complex CAD model for real-time rendering is the most strategic aspect. Reducing the polygon number allows the game engine to render a CAD model with a better performance. But parallel with this benefit is a side effect that sometimes it leads to the lost of details. Low polygon model makes a complex 3D form, such as tent and dome structures, look cubical and none photo realistic.

Prospect of VRAD

Another constrain is the poor connection between CAD software and game engine. Because neither AutoCAD, Revit nor Micro Station has functions to optimize a 3D geometry or control its level of details, students have to learn Alias Maya or 3D Studio Max in order to control the polygon number. This additional step increases the learning time.

There are many other challenges and potentials of VRAD. For example, how to keep students' interest focusing on the 3D form studies instead of rendering technologies, how to embed 3D scanner and laser cut to allow projects to go across analog and digital. We will continuously conduct our investigations and experiments in the future.

By the time of writing this paper, new projects are still ongoing. Teaching methods from previous quarters have been refined constantly in the digital design courses and used as a starting point in the following quarter. Student can gain spatial experiences in an interactive digital environment. Most important, they can understand that digital model is not just for generating good-looking renderings or animations for presentation purpose, but becomes a dynamic virtual prototype which they can explore, discover, evaluate and adjust. It integrates with the cumulative sequences of knowledge in the design context and is increasingly involved into various design phases.

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APPENDIX

Appendix fig.: Screen captures from real-time in Unreal engine. 56 frames per second

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