Visualization of Architectural Models in Virtual Reality

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***Abstract*—With the recent resurface of virtual reality multiple projects have been developed to make use of the capabilities given by head-mounted displays such as the Oculus Rift or the Project Morpheus, the previously mentioned projects range from video games, to more academical, like the display of historical set ups using such technologies for instance. This project aims to make use of the Oculus Rift to display housing models. These models are an important part of a well-established practice in Colombia where construction companies build a single apartment or house to show potential clients how the construction will look when the project is finished. This practice however, takes a considerable amount of time and when the construction has finished the model is demolished, creating a lot of wastes. Using the Unreal 4 Engine and computer graphic algorithms the project intends analyze the viability of creating a tool to successfully display realistic virtual models of said construction projects on the Oculus Rift in order for the user to have an enjoyable experience and also give them the ability to visualize how the project will look like.**

***Keywords*—Oculus Rift, Virtual Reality, 3D Models, Computer Graphics, Housing.**

I. Introduction

Virtual reality is a concept that can be traced back to the 60's and has had a relatively slow development. However, this has changed in recent years. Tech giants such as Facebook and Sony are seeking to have a share on this new market with projects such as Oculus Rift[3] and Project Morpheus [2] respectively. Considering the growing interest in such projects, there are plenty opportunities to

With the constant urban growth of the city of Cali, Colombia. It is evident that projects involving construction are going to keep increasing as the demand for new housing and recreation building projects rises. The creation of housing models, a building that intends to show how the project will look on its final stage, is a practice that has been used for countless years as the main way to show a client what he or she will be buying. However, this practice is not efficient, not only it consumes a considerable amount of time in the process of building the housing model, but also the housing model is destroyed, creating a big amount of waste of material in the process.

The recent breakthroughs in the area of virtual reality might allow to bring new and innovative solutions to issues in areas such as telepresence, gaming, education, among others. However, it is necessary to determine whether virtual reality does improve the previous established solutions, such as the practice of creating a housing model.

This project aims at creating a prototype of a 3D architectural model and studying the acceptance among different types of users, which in this case will be people with and without technical knowledge regarding engineering topics and computer graphics. Additionally, certain aspects related to Virtual Reality are also evaluated, such as overall graphical quality, simulation sickness problems and perceived realism by the users.

This paper is structured as follows: Section II analyzes some preliminaries. Section III describes the system and some design considerations. Section IV presents a very brief summary of the development and implementation of the system. Section V presents tests and results. Finally, Section VI presents conclusions, followed by future work in section VII.

II. Preliminaries

III. Design Considerations

This section describes the core requirements envisioned with the project, as well as some design considerations that were useful to evaluate the viability of creating a prototype of the visualization tool.

A. Overview

The initial Scope of the project involved the creation of a 3D virtual environment utilizing an already existing 3D architectural model. This model needed to be properly structured and organized by utilizing a proper 3D authoring tool for it to later be placed in a 3D virtual environment. The system needed to be developed in a game engine with Oculus Rift support. Additionally, the system had to be creating while taking into account virtual reality considerations such as the ones mentioned in the previous section. And finally, the system needed to utilize computer graphic techniques to enhance the perceived realism by the users. The entire project idea was to evaluate both the realistic virtual environment created in a powerful game engine and the acceptance of the people who explored it by using the head-mounted display called the Oculus Rift.

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B. Design

The main part of the project was to create a 3D virtual environment as realistic as it could be created. The initial model, which was created in SkechUp, and was kindly provided to us by architect David Tobar, as it is shown in figure X. The model itself could not be used unless it could be adapted to what was needed for the project, as it had many different problems, specially problems regarding shadows, lighting and textures. The design of the application consisted mainly on deciding what to do to fix these problems.

The design was divided in two parts, the interaction and the vividness of the application. Basically, the model needed to be fixed and adapted to look realistic, in other other words, fulfil the vividness desired for the application. However, this alone was not enough, as the application had to include interaction, and not only focus on realism itself. The realism was bound to how much the model could be improved and how much hardware was available to use in the computer where the system was being developed. And the interaction was not very clear, and in fact there were two considerations. The first consisted in a keyboard and a mouse, and the second was a to use a controller to let the user move, explore and interact. Peripherals such as Kinect or other external hardware were out of the scope, as they were not available to us and/or did not contribute with the desired latency for this project. Additionally, interaction was focused on exploration mainly, therefore no other additional interaction such as opening a door, or turning the lights on and off was added. This was not ideal, but it was decided to give the vividness of the application more attention and interaction was left to the minimum.

IV. Implementation

The implementation of the project was divided in two basic steps: the first, was to adapt the original model so it could be used properly in Unreal Engine, the second step was to use features from Unreal to create a visualization that would accommodate to certain expectations (these expectations were mostly defined by user feedback during the tests and prior surveys).

A. Model adaptation

The geometry of the model was re-checked and fixed; some polygons were removed altogether because the amount of time that was required to fix them exceeded the time scheduled to adapt the model. The original furniture included was replaced by models obtained from open source sites or the Epic Games demos which had a better quality as they were mostly made by professionals in this field and as the tests showed had a very positive impact on the final users.

Finally the model was completely UV mapped so it could be textured using the powerful material system included in Unreal.

B. Model Customization

With the model functioning on Unreal Engine came a process of texturing, adding materials and customizing some of those materials to increase the visual impact it had on the user. In addition to the addition of the materials, pre-existing models were added, and were carefully placed to enhance the immersion, taking in consideration the results of the tests performed in [9] which showed that if the user achieves a certain level of immersion, disruptions on graphic quality would have a lower chance of breaking the immersion that was already obtained.

Finally, multiple illumination concepts were applied to the project in order to have realistic shadows and reflections; Lightmass Global Illumination, Reflection Environments, Ambient Occlusion and Ray Traced Distance Fields were among the techniques applied to enhance the graphic fidelity of the environment.

V. Tests and Results

This sections discusses the two tests that were done throughout the development of this project, as well as the main results and observations.

A. First Test

Following the first iteration of the development, which included: the architectural model, basic furniture and basic lighting settings, a survey was created to determine the user perception of the project on its most basic form and improve on all the feedback obtained from it.

For the survey 15 people with no technical knowledge and 15 people with technical knowledge about engineering and computer graphics were surveyed. In the survey they were asked about the perceived graphical quality regarding some characteristics of the scene, with level 1 being non-realistic and 5 being realistic.

The following questions are the ones that were intended to be qualified with a numerical value from one being the lowest to 5 being the highest score.

- How would you qualify the overall realism on the scene?
- How would you qualify the illumination observed on the scene?
- How would you qualify the reflections on the scene?
- How would you qualify the shadows observed on the scene?
- What level of realism would you place the furniture at?

To finish the survey two open question were asked: one regarding things the user did not like, and the second things that the user thought could be improved. The questions are the following:

- Which things in the project were not to your liking?
- Which of the project's features would you improve?

Not many issues or improvements were found regarding the open questions, most users complimented the work done and liked the idea. However, one thing in particular that was brought to light by these two questions, was regarding that the non-technical people were not as interested in the graphical quality of the project, but rather in things such as the decoration of the house. They particularly did not like that the space was so big and yet so empty. The interesting part of this test was regarding the movement; most people had problems moving around (this particular issue was addressed with the usage of a Controller, See figure **??**), yet only a 14% considered it to be an issue, not a single person mentioned something regarding collisions or any other technical yet visible features.

Most of the issues identified by the users were things that are commonly seen in video games, as the project was on an unfinished state, some of them were overlooked in order to have the test to be performed on time. Its also interesting to note that a considerable amount of people did not find anything wrong with the project. On contrary, people that tested the project considered that plenty of the features could be improved, since most of them had gaming backgrounds some of these features were understandable, since they did not feel as satisfied by simply walking around the model but requested things like Jumping or better controllers.

B. Second Test

After one month of addressing all the issues that were identified during the first phase of testing and fixing multiple problems with the Oculus Rift performance a second test was performed. This test was done with the objective of identifying if previous issues were solved, if new ones were created and how comfortable the users were using the Oculus rift. The test was split in three parts: closed questions that asked about the scene quality and the virtual reality experience, closed questions that aimed to obtain information regarding the Oculus Rift effect on people and the same open questions done the previous subsection.

In addition to the already stated changes, new assets were brought in to fill every empty room. As a result of many non-technical people in the previous test criticizing the project due the lack of furniture, decorations and even materials. For this reason, it was also decided to fill every room with at least three or more assets and use no more than three materials with achromatic colors if possible.

For this test, most of the lighting features were added. The project was mostly in its final state when it was decided to perform this test. Aside from a technical issue that made the Oculus Rift frame rate to oscillate between 25 to 35 frames per second in different areas of the environment, the entire project was nearly finished. Also, a controller was used to aid the need of simplifying movement in the virtual scene.

C. Results

VI. Conclusion

During the development of this project multiple issues came into light that were not considered as the project started. First of all, modelling tools such as Sketch Up or AutoCAD do not invite architects or civil engineers to model buildings appropriately for a post process in a more advanced modelling software, the lack of UV maps makes it impossible for a smooth transition to a display tool, and this process makes the lack of an automated tool to avoid this tedious phase to take a considerable amount of time fixing these problems. Therefore, to reduce the time of development on a project of this type, the assets must be properly modeled, which is a problem as the majority of the assets were obtained from various assets stores that offered them for free.

Another equally important objective of this project was to use computer graphic techniques. Global illumination algorithms and other illumination features provided by the engine were used to enhance the perception of realism of the 3D architectural model displayed in the virtual environment to create an astonishing virtual environment.

The Unreal Engine 4 provides developers with features that are both efficient and robust, with the exception of some dynamic features that were not always fully optimal due to GPU high demand and very few limitations like non-uniform scaling and poor quality in large objects for instance. In despite of these limitations, global illumination was achieved without many complications. The main problem that arose after using these features was the Oculus Rift itself, as it demanded top-notch hardware, and so a balance between performance and quality was needed.

It is important to note that with this project it was intended to analyze the viability of a tool to aid with the problem of visualization of architectural models using virtual reality. This certainly includes a laborious process of transforming a simple 3D architectural model into a one that could be perceive as realistic, and so this process alone implied a lot of manual work and the use of software without much technical expertise. Also, when lighting features were added to the scene, specially when dynamic lighting was added, a lot issues appeared, such as deformed shadows, algorithms not working properly due to bad organized model structures and limited supported components for Ambient Occlusion. Additionally, the main concern of this work was the Oculus Rift interaction and usability, in order to give users a pleasant experience. This however was a huge problem throughout the project, having to work with a rather unstable software created by Oculus VR that had too many limitations regarding compatibility, stability and even some visualization issues, such as graphical quality and framerate problems limited the vividness of the scene.

As far as viability goes, the project received very good reviews, the users felt it was a good idea albeit they mentioned a lot of improvements if the prototype was to ever be used

as a sales tool, it can be considered to be a few steps away from being a tool that can actually be used commercially. On the technical side there are multiple shortcomings: the frame rate drop is unacceptable as it makes people get simulation sickness, making the tool unpractical; the constant updates make it a problem too, since at the beginning of the project laptops were supported by the Oculus runtime and the project ran well enough on them, but as a new version came out, laptops were not supported at all. Stability is a must if the process is to be formalized, a better computer might improve the frame rate issue and give the project more options to include more models without taking a hit on performance.

VII. Future Work

The project obtained some impressive acceptance among the surveyed people and there is definitely room for improvement in projects related to this one.

Optimizations on the illumination and shadowing would help solve the problems faced regarding performance.

Both test results showed an interest in having a more visually attractive house, a lot of models were not used or discarded due to the increase on performance issues as the mess count increased, with a more powerful machine and custom-made meshes some of these issues can be addressed.

The sound in particular was one of the features that was neglected the most, the project had a background sound that was useful when the user was outside the house since it sounded as if they were on a garden, nonetheless the lack of more detailed sounds such as sound steps on different surfaces, screeching doors, or noises commonly heard around a normal home would highly increase the immersion felt by individual users.

An intuitive movement scheme would be one of the most interesting and complex potential projects; people struggled with moving around the project. Multiple solutions were envisioned, the use of mouse and keyboard, a controller in conjunction with the head track of the HMD and even the controller alone to handle the movement and head track, none of them were completely satisfactory as people still got confused. We consider that the answer would be to use the Oculus Rift and a camera like the one used with Microsoft's Kinect to track the movement of people. However, the biggest issue with this is the wiring, as the wiring is necessary to reduce delay and other interference wireless protocols have, which make the display useless as it can not display in real-time the user's movement.

Lastly, a more complex interaction system (which includes grabbing elements of the world or having the elements react to user input) would certainly increase the immersion of users and could leave a more noticeable impact on them.

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References

[1] CrazyBump normal mapping. http://www.crazybump.com/. Accessed: 2015-06-23.

[2] PlayStation project morpheus. http://blog.eu.playstation.com/2015/0 Accessed: 2015-06-23.

[3] Oculus VR development kit 2. https://www.oculus.com/en-us/dk2/. Accessed: 2015-06-23.

[4] Unreal Engine 4: particle systems. https://docs.unrealengine.com/latest/INT/Engine/Rendering a. Accessed: 2015-08-23.

[5] Unreal Engine 4: virtual reality best pratices. https://docs.unrealengine.com/latest/INT/Platforms/VR/Con b. Accessed: 2015-09-10.

[6] Sketch Up help. http://help.sketchup.com/en/article/36260. Accessed: 2015-06-23.

[7] Unreal Engine 4 lighting and shadows. https://docs.unrealengine.com/latest/INT/Engine/Rendering Accessed: 2015-09-20.

[8] Alan Chalmers and Andrej Ferko. Levels of realism: From virtual reality to real virtuality. In *Proceedings of the 24th Spring Conference on Computer Graphics*, SCCG '08, pages 19–25, New York, NY, USA, 2010. ACM. ISBN 978-1-60558-957-2. doi: 10.1145/1921264.1921272. URL http://doi.acm.org/10.1145/1921264.1921272.

[9] Kevin Cheng and Paul A. Cairns. Behaviour, realism and immersion in games. In *CHI '05 Extended Abstracts on Human Factors in Computing Systems*, CHI EA '05, pages 1272–1275, New York, NY, USA, 2005. ACM. ISBN 1-59593-002-7. doi: 10.1145/1056808.1056894. URL http://doi.acm.org/10.1145/1056808.1056894.

[10] Wikimedia Commons. Yaw motion in an aircraft. https://upload.wikimedia.org/wikipedia/commons/5/54/Fligh 2007. Accessed on 04-04-15.

[11] Wikimedia Commons. Play station 4. https://en.wikipedia.org/wiki/PlayStation_4, 2013a. Accessed on 04-04-15.

[12] Wikimedia Commons. Normal mapping. https://commons.wikimedia.org/wiki/File:Normal_map_exampl 2013b. Accessed on 04-04-15.

[13] Mohamed Elhelw, Marios Nicolaou, Adrian Chung, Guang-Zhong Yang, and M. Stella Atkins. A gaze-based study for investigating the perception of visual realism in simulated scenes. *ACM Trans. Appl. Percept.*, 5(1):3:1–3:20, January 2008. ISSN 1544-3558. doi: 10.1145/1279640.1279643. URL http://doi.acm.org/10.1145/1279640.1279643.

[14] James D. Foley, Richard L. Phillips, John F. Hughes, Andries van Dam, and Steven K. Feiner. *Introduction to Computer Graphics*. Addison-Wesley Longman Publishing Co., Inc., Boston, MA, USA, 1994. ISBN 0201609215.

[15] Diego Gutierrez, Veronica Sundstedt, Fermin Gomez, and Alan Chalmers. Modeling light scattering for virtual heritage. *J. Comput. Cult. Herit.*, 1(2):8:1–8:15, November 2008. ISSN 1556-4673. doi: 10.1145/1434763.1434765. URL http://doi.acm.org/10.1145/1434763.1434765.

[16] Donald E. Knuth. Computer Programming as an Art. *Communications of the ACM*, 17(12):667–673, December 1974.

[17] Venkat Krishnamurthy and Marc Levoy. Fitting smooth surfaces to dense polygon meshes. In *Proceedings of the 23rd Annual Conference on Computer Graphics and Interactive Techniques*, SIGGRAPH '96, pages 313–324, New York, NY, USA, 1996. ACM. ISBN 0-89791-746-4. doi: 10.1145/237170.237270. URL http://doi.acm.org/10.1145/237170.237270.

[18] Hristo Lesev. Classification of global illumination algorithms. *University Press "Paisii Hilendarski", Plovdiv*, .:., 2010.

[19] Hector E. Medellin. Transformaciones en 3d. http://galia.fc.uaslp.mx/ medellin/Applets/Trans3D/transf 2007. Accessed on 04-06-15.

[20] Alessandro Mulloni, Daniele Nadalutti, and Luca Chittaro. Interactive walkthrough of large 3d models of buildings on mobile devices. In *Proceedings of the Twelfth International Conference on 3D Web Technology*, Web3D '07, pages 17–25, New York, NY, USA, 2007. ACM. ISBN 978-1-59593-652-3. doi: 10.1145/1229390.1229393. URL http://doi.acm.org/10.1145/1229390.1229393.

[21] G. Papaioannou. Real-time diffuse global illumination using radiance hints. *High performance graphics 2011*, .:., 2011.

[22] Gabriel Peyre and Laurent Cohen. Geodesic computations on 3d meshes. http://www.cmap.polytechnique.fr/ peyre/images/test_remeshing.jpg, 2006. Accessed on 04-04-15.

[23] Eva Pietroni and Andrea Adami. Interacting with virtual reconstructions in museums: The etruscanning project. *J. Comput. Cult. Herit.*, 7(2): 9:1–9:29, June 2014. ISSN 1556-4673. doi: 10.1145/2611375. URL http://doi.acm.org/10.1145/2611375.

[24] James Ferwerda Program and James A. Ferwerda. Three varieties of realism in computer graphics. In *In Proceedings SPIE Human Vision and Electronic Imaging '03*, pages 290–297, 2003.

[25] PS4Daily. Project morpheus vs htc vive vs oculus rift. http://ps4daily.com/2015/03/project-morpheus-vs-htc-vive-vs-oculus-rift/, 2015. Accessed on 04-04-15.

[26] J. Sans. F.; Esmitt Ramirez. Real-time diffuse global illumination based on voxelization. *Computing Conference*, .:1,12,7–11, 2013.

[27] Clifford So, George Baciu, and Hanqiu Sun. Reconstruction of 3d virtual buildings from 2d architectural floor plans. In *Proceedings of the ACM Symposium on Virtual Reality Software and Technology*, VRST '98, pages 17–23, New York, NY, USA, 1998. ACM. ISBN 1-58113-019-8. doi: 10.1145/293701.293704. URL http://doi.acm.org/10.1145/293701.293704.

[28] Robert F. Tobler. Radiosity - ray tracing. https://www.cg.tuwien.ac.at/research/rendering/rays-radio/, 1997. Accessed on 04-04-15.

[29] Oculus VR. Oculus rift dk2. https://www1.oculus.com/order/, 2014. Accessed on 04-04-15.