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COMBINING LIGHTING, MEDIA TECHNOLOGY AND ARCHITECTURE

Use of Virtual Reality for showcasing indoor and outdoor lighting proposals

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Abstract:
As a lighting designer, using the correct tools for presenting different concepts to the clients is crucial. The technology offers us the possibility to digitally implement prototypes that can define the overall idea of the final project without implementing physical mock-ups. As the technology is continuously evolving, the designers have to adapt and take advantage of the new tools and possibilities.
Nowadays, the Virtual Reality technology became popular, and it found its applicability in many industries. This paper is trying to define to which extent the VR can be used by the lighting designers in their working process.
The research will focus on the design and implementation of a prototype that is using VR technology in combination with interactive elements to create a digital space that can be utilised by lighting designers to present their ideas to the clients. Compared with previous tools, the proposed solution will offer the possibility to the users to freely explore the space while observing the lighting designs in real time. The paper will describe the different testings that were conducted to find the benefits and limitations of the proposed solution.
The results show that the system has the potential for being used in the working process of the lighting designers and with further improvements, can represent a reliable tool.

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Abstract

Objective: As a lighting designer, using the correct tools for presenting different concepts to the clients is crucial. The technology offers us the possibility to digitally implement prototypes that can define the overall idea of the final project without implementing physical mock-ups. As the technology is continuously evolving, the designers have to adapt and take advantage of the new tools and possibilities.

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Conclusion: The results show that the system has the potential for being used in the working process of the lighting designers and with further improvements, can represent a reliable tool.

Keywords - Virtual Reality, Lighting Design, Interaction, Dynamic Lighting

Introduction

To be a lighting designer means to have the ability to come up creatively with lighting solutions for a space that satisfy the needs and requirements of the users of a particular location. The design process and presentation of an idea plays a significant role in the work of a lighting designer and represents a major point of convincing the clients that the lighting solutions are what they need and further possibly making them invest into it.

In their process, the designers have to use different tools that can help the clients understand what is the concept and further comprehend how the actual implementation of the idea will be. One way to do this is by creating simulations and visualisations of the installations. In their paper, M. Yamamoto & D. Lambert discuss how the product appearance can have an impact on its evaluation. Their results suggest that attention paid to product aesthetics may have a payout regarding sales performance. Even if their research is focused on the industrial goods, the idea can also be applied in the design and presentation process of a lighting concept. The visual impact of a lighting solution can be more valuable to the client than its functionality, so an excellent presentation of it can help the developer to offer an overall image of his ideas. (Yamamoto, & Lambert, 1994)

Nowadays, using computer-generated visualisations of the space, represents the most cost and time efficient way to convey the lighting ideas. This technique became more and more popular in the architecture, engineering and construction industries, covering the whole lifecycle of a product from the presentation of initial concepts to the final stages of production and can also extend to maintenance issues. In their paper, D. Bouchlaghem et at. describe the three-dimensional representations as a tool that can be used by design teams to communicate design intent to clients and to compare and evaluate design options. (Bouchlaghem, Shang, Whyte, & Ganah, 2005) In the industry of lighting design, the same principles are applied, and similar techniques are used. Renderings, interactive visualisations or 3D simulations conveys precisely the ideas and can help in the decision making process.

In the last few years, the Virtual Reality technology appeared, and it has been continuously improved. The VR was initially created as a tool for the gaming industry, as a truly immersive and entertaining way to present the content. In time, the developers found its applicability also in other areas such as medicine, defence, design, where the advantages of VR can improve the working process.

Virtual Reality (VR) offers lighting designers a more immersive way of presenting their ideas to the clients. To have the immersion in VR, the simulation has to create a realistic experience for the users regarding the freedom of exploration (movement, 360-degrees view) and in the same time an accurate and realistic visual data. Previous researchers suggest that realistic visual data can be achieved using pre-rendered visualisations, but in this way the user can observe the space only from fixed positions, which can represent a limitation for the immersion in VR, and at the same time losing valuable data that the user could gather by exploring the 3D space. Using real-time renderings will affect the accuracy of the lighting information that the user will get because the current technology offers only prototypes that manage real-time calculations for light, but will provide the freedom for the user to explore the space and to visualise the lighting designs from any desired perspective. In the same time, the technology offers the possibility of communicating inside of VR and collaborating with the other users. Based on this observations the following problem statement was formulated:

“Offering the freedom to the users to explore a virtual space in real-time instead of presenting it using static 360° renderings can enhance the immersion and can provide to the lighting designers a closer to reality way to introduce the lighting solutions to the clients.”

To analyse the problem statement, the following research questions were formulated:

1. To which extent the user can manipulate the light in VR to maintain accurate/close to reality lighting designs?

2. In which scenarios/situations the freedom of exploring the VR space is more beneficial?

In the following pages this problem will be analysed from a theoretical perspective by presenting how the VR technology has been used by designers in different projects and how it can be beneficial for the lighting designers and at the same time how is applicable in other fields of study. Further, based on the analysis and theoretical framework, the development of a prototype will be presented and further tested to assess the research questions. At the end of the paper, the final results will be discussed and concluded.

Theoretical Framework

A Lighting Designer uses light to create the desired atmosphere for a particular location. The light can be artificial or real, practical or purely aesthetic, subtle or intense. The light can evoke an emotion or set a mood. Altogether, a Lighting Designer can control different properties of light such as intensity (brightness of the light), colour (temperature of the light), distribution (beam and direction), and movement (change of lighting properties over time).

You can say that Lighting Designers are light artists. But before starting to create or change the old light installation with their new ideas, they need a way to convey their vision of the project to their clients, to convince them and further to have an agreement for implementing it in real life. Presenting an idea without using some specific tools can create misconceptions for the clients and further the rejection of a possibly good design. The answer to this concern lies in technology and more specifically in computer processing and visualisation software that the lighting designers can use.

The Computer-generated imagery (CGI) is a function of computer graphics to create or digitally enhance all sorts of media files (images, videos, simulator, games, etc.). The visual scenes may be dynamic or static and may be two-dimensional (2D) or three-dimensional (3D), depending on the requirements of each project.("Computer-generated imagery", 2017)

In the case of Lighting Designers, the appropriate direction was to use 3D computer graphics to have a working environment where they can simulate the real location but in a more controlled and cost-efficient way. Using those tools, the lighting designer enters the light schema into the visualisation software and then enters the ground plan of the location, giving as much three-dimensional data as possible (which helps in creating complete renderings). This creates a 3D model in digital space that can be lit and manipulated. Using the software, lighting designers can build and use any desired lights to convey real light in the 3D model with the ability to define parameters such as colour, focus, colour temperature, beam angle, etc. The designer can then take renderings or "snapshots" of various looks that can then be printed out and shown to the clients.

During the years, the technology evolved rapidly offering more and more tools for creating photorealistic visualisations and renderings. Rendering Engines such as V-Ray, Maxwell, RenderMan, etc., provide all the lighting, shading and rendering tools that an artist need to create professional, photorealistic imagery, but, at the same time, those tools require high computational power to work properly. In this case, the outcome of the artist is a 3D visualisation that can be further presented to the client as a printout or a simple image. ("3D render engines: top 7 choices from pros l ArchiCGI", 2017)

Even though static 3D renderings of a location can convey the overall lighting vision for a particular space, they still have boundaries in making the clients completely have an understanding and feeling of how the location is going to look.

As the technology is continuously evolving, new ways of conveying to the users the graphical data have been implemented, improving the visual quality or offering more immersive ways of visualising the information. In the case of lighting designers, many of those technologies can be applied and at the same time improve the workflow and the output of their designs. Some of the technologies are: High-Resolution Displays, HDRI Displays, Augmented Reality (AR) or the Virtual Reality (VR).

A more immersive way for conveying the designer's idea is the dynamic visualisation. This can be achieved by using an engine which can render in real time the environment while giving the possibility to the user to explore the space. This way of conveying the design includes many elements of gamification such as exploration of the space or interaction with the different objects in the scene.

"The Father of Virtual Reality" Morton Heilig had contributed a lot to the evolution of virtual reality. He was not as famous in the 50s and 60s when he was alive as he is nowadays. In 1957 he invented and in 1962 patented the "Sensorama Simulator" a simulator based on virtual reality or as Heilig called this invention "the cinema of the future". In the 50s when the Sensorama Simulator was invented there was not a lot of 3D movies, most people still had a black and white TV, and that led to the Sensorama having only a few options to ride, for example, a bike or motorcycle. Heilig Simulator, if we look at it from the perspective of income, failed. There were not enough investors to support his invention, and that led to Heilig's wife still paying off the debt two decades after her husband's death. However, the Sensorama Simulator had a lot of inventions: a moving seat, stereo speakers, vibrations, 3D view, wind and even a scent simulator. It was way ahead of its time and is still working today and can be tried in the Universal Studios in the United States. (Fearn, 2017)

Until 2012, the dynamic visualisations could be conveyed to the users only using standard flat screens or other tools which still had a limitation in the immersion offered and the feeling of being in the actual space. In this year, the first Virtual Reality headset was released as a Kickstarter project by the company Oculus VR. This device could offer stereotypic images with 110° field of view and 6DoF head tracking systems. Even though this was a groundbreaking technology, the poor resolution of the pictures wasn't ideal for 3D visualisations. ("Oculus Rift | Oculus", 2017)

Since then, the VR technology has been considerably improved, and different companies started to offer better and better quality and experience for their users. One of the devices is HTC Vive which is a high-end VR headset designed to utilise "room scale" technology to turn a room into 3D space via sensors. the device allows the user to navigate naturally, the ability to walk around and use motion tracked handheld controllers to manipulate objects vividly, interact with precision, communicate and experience immersive environments.

Types of VR

Many large enterprises around the world started to develop their own VR headsets, but since 2016, HTC Vive and Oculus Rift offer the top of the line experience both regarding image and product quality. In the same year, the two companies developed VR platforms that are user-friendly and provide connectivity with various applications. As the two products are mostly used by the clients for entertaining, the gaming industry adapted and offered creative and interactive games through the SteamVR platform (for HTC Vive) and OculusVR (for Oculus Rift). ("SteamVR", 2017)

Except for the entertainment applicability, the VR technology has a variety of potential benefits for different industries. In their paper, T. Schultheis & A. Rizzo observe how VR is used for rehabilitation assessment, treatment and research. Through its capacity to allow the creation and control of dynamic 3-dimensional, ecologically valid stimulus environments within which behavioural responding can be recorded and measured. VR offers clinical assessment and rehabilitation options that are not available with traditional methods. (Schultheis, & Rizzo, 2001)

Another paper by K. Valentino et al. present the development of a VR flight simulator which simulates the environment of real flights while being more portable and accessible than the conventional flight simulators. Also, the simulation can provide intense sensations like being in a plane cockpit increasing the realism and the interaction of the users. (K Valentino et al., 2017)

Many other applicabilities for the VR technology can be mentioned, and in every idea, it can be easily observed that the VR can represent an essential tool. The VR is under continuous evolution since 1962, but nowadays it can be concluded that the head mounted displays got to a stage of development reliable for the developers and their clients. The technology will continue to be improved, but for the purpose of this research, the current best products on the market will be assessed.

Nowadays, the VR technology found it's usability in various creative ways also for the Lighting Designers, and this can also represent a new high aspect in the process of developing their designs and at the same time presenting it in a more immersive and convincing way to the clients.

One area of the VR technology that started to be more and more popular includes the 360° visualisations, videos or renderings. In combination with a VR headset, this kind of visualisations can immerse their users in the space and add value to the feeling of realism. This way of presenting design ideas can be powerful and can have a high quality. The reason for this is that all the displayed content can be pre-processed utilising techniques such as 360 degrees 3D rendered images created using rendering engines (e.g. V-Ray). Further, it can be modified and enhanced in the post-processing stage.(e.g. Photoshop) In the end, the final result can be presented to the clients utilising a VR headset. Even though this process can offer high-quality content, it still limits the immersion of the users by not giving them the freedom of exploration and by keeping them in static points from where they can observe their surroundings. This means that they are the observers in the VR space and not a part of it.(Jann, 2017)

What distinguishes VR from adjacent technologies is the level of immersion it promises. When VR users look around — or, in more advanced headsets, walk around — their view of that world adjusts the same way it would if they were looking or moving in real life. This means that VR offers the feeling of presence in the 3D world by involving more stimuli for the user (vision, sound, equilibrium, etc.). The previously described systems offer a high level of immersion for the users, but they don't provide the real-time rendering of images and the freedom of exploring the space. ("What are the differences among virtual, augmented and mixed reality?", 2017)

Use of VR technology

This technology found it's applicability in the company ArchVirtual which offers a unique marketing strategy for the real estate companies. They create 3D simulations of the apartments in which the clients could move and give them the possibility to explore the space in VR. Their idea of business is well described in the following paragraph:

"The Oculus Rift virtual reality application Arch Virtual built for our team gave us complete confidence that what we were about to build was fully understood by all parties. Being able to communicate everything from intricate details to large-scale spatial implications in an immersive way gave a much better understanding than could have otherwise been realised.

In the end, when the client walks into their new space, they won't be experiencing it for the first time. "

("Virtual Reality Applications for Oculus Rift and HTC Vive - Arch Virtual", 2017)

Start VR is an Australian company that has developed the product EDGE28, a dedicated VR App to be used with virtual reality technology as part of the sales process in the real estate business, allowing prospective buyers to experience the space even before construction has started. ("Revolutionising Virtual Reality Real Estate - Start VR", 2017) As it is mentioned on their web page, the real-estate industry previously offered the possibility to visualise the design of the new locations in 360-degrees interactive video tours. With the development of EDGE28, the experience is fully immersive, providing the opportunity to the clients to explore the space and feel what they are going to buy. (Figure 1)

In their paper, P. Dunston et. al. (2011) analyse the use of technology for presenting proposed designs for healthcare facilities without having to implement full-scale physical mockups (PMUs) physically. They describe that the use of three-dimensional visualisations can offer to the stakeholders of the institutions the opportunity to comprehend proposed designs more clearly during the planning and the design phases, thus enabling the greatest influence on design decision making. (P. Dunston et. al., 2011)

This kind of technology can be easily adapted for the Lighting Designers by combining the architectural representations of the space with the lighting elements. With the current technology, the developer can simulate completely interactive lighting systems and can present different variations of the lighting schemes.

FIGURE 1: LEVEL OF DETAIL IN AN INTERIOR DESIGN PROJECT

This research tries to investigate what are the elements that can create a more immersive experience for the clients and how can this new technology can be used to help the lighting designers convey their ideas in a more creative and convincing way.

Methods

To answer the proposed research questions, the idea for this project was to develop a prototype which will serve as a tool throughout the research. Based on the previous studies, the prototype can be considered as a platform that has the capabilities to simulate the lighting scenarios in real time, offering the possibility to the lighting designers as well as their clients to explore the space. The goal of the project is to achieve realistic lighting simulations which have to be completely interactive. At the same time,

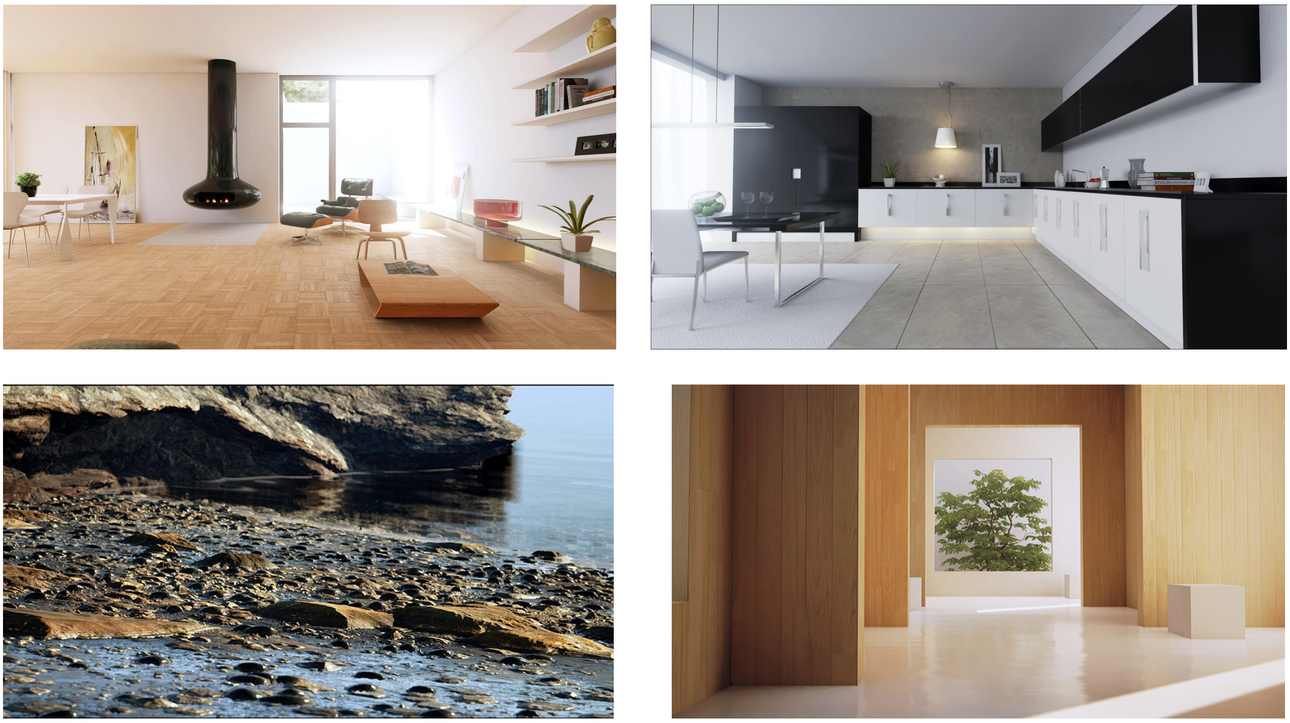

FIGURE 2: VISUALISATIONS OF DIFFERENT PROJECTS WHICH PRESET THE IMAGE QUALITY THAT CAN BE ACHIEVED UTILISING THE UNREAL4 GAMING ENGINE

the platform has to be intuitive, easy to use and scalable.

Based on the research, the best starting point for building such a platform is to use a game engine that offers a reliable connection with the VR systems and which has a robust lighting system that can provide realistic simulations. Nowadays, many gaming engines reach this expectation, but for this project the choice was Unreal Engine being an industry-leading engine which offers photorealistic renderings in real-time, possibility to rapidly prototype and create interactions using blueprints and which has advanced optimisations for VR.

Unreal Engine was used throughout the years to create astonishing games that present beautiful environments with realistic lighting conditions. Even if the engine is designed for creating games, artists and designers found its usability for showing their creations. Instead of using 2D renderings for conveying their ideas, they create 3D environments which can be more accessible and interactive. Pierre Bosset presented in his article “The art of Koola” the work of one artist which call himself Koola. The article shows different indoor or outdoor environments which have a level of detail which can be compared with photo-realistic renderings (Fig 2). The advantage of his work is that the users that observe the presented space explore it and in the same time get a more immersive experience of what the artist tries to showcase. On their blog/online shop, UE4Arch present many architectural projects that can be inspiring and which present in the smallest details the idea that an architect or designer had for that particular space.(Figure 2). ("The Art of Koola", 2017)

Prototype

The purpose of this research is to offer to the lighting designers a tool that can be used for conveying their ideas to the clients. Knowing that the work of a lighting designer is directly connected with the work of the architect, it can be considered that Unreal Engine can be a valuable tool also for them. Following this way o thinking, the simulation will offer different tools for interacting with the elements of the environment and at the same time the possibility to experience the surroundings in a fully immersive VR experience. The design and evaluation will be presented in the following part of the paper.

Implementation

The overall idea for the prototype is that the lighting designer can present any desired scene using this tool but for the

purpose of this research, only one indoor scenario will be analysed and further tested with two systems/environments.

The development of the prototype includes three different stages. The first step is to calibrate the two environments to have similar lighting conditions. The 360-degrees VR environment uses pre-rendered images that were created using precise values for the characteristics of light (luminous flux, colour temperature, beam angle, etc.) and they were rendered using engines that can offer pre-calculated and precise global illumination. The proposed prototype will use those renderings as a calibration/reference point for the lighting. This method was chosen because Unreal Engine doesn't offer any tool for measuring precise characteristics of light. The scene in UE4 will be developed respecting the scale of the meshes and their exact position as in the 360 degrees renderings, in order to have consistent data.

Global Illumination

One of the most important characteristics of lighting is the indirect illumination/global illumination (GI). The GI refers to the rays of the direct light that are reflected by other surfaces in the scene, whether reflective or not. In 3D computing, the GI represents a set of algorithms used to add more realistic lighting in the 3D space. This kind of algorithms require a big amount of processing power and usually take considerable time for achieving correct bounces in the renderings. In UE4, the GI is available only as a pre-calculated option, which means that the lights have to be baked into the scene. This way of controlling the lights creates realistic lighting conditions, but this means that the fixtures remain static/non-interactive.

This aspect represented the first limitation that was encounter in the development process. To create a tool usable for the lighting designers, it was necessary to use real-time global illumination (GI) in the scene. Because the user will have the possibility to explore the space and in the same time to interact with the lighting, the global illumination has to be adaptive based on the position of the user and its perspective of view. Unreal Engine doesn't

FIGURE 3: DESIGN OF THE SCENE UTILISED AS THE FIRST TESTING SAMPLE

offer such a functionality out of the box, but companies such as Geometrics or Nvidia started to research and implement prototypes that provide real-time GI for gaming engines. Even though the software offered by Geometrics ("Enlighten I Enlighten I Real Time Global Illumination Solution", 2017) is more stable and provides better performance, the company doesn't allow access to it for the individuals or small businesses. Because of this reason, the plugin couldn't be implemented into the prototype, and it won't be discussed throughout the project.

To achieve the dynamic GI in the scenes, the plugin Voxel Global Illumination (VXGI) developed by Nvidia, was used. The Nvidia VXGI is an implementation of a global illumination algorithm known as Voxel Cone Tracing. The plugin is currently designed only for Windows platforms and works with DirectX11 dependencies or above. The key features that the plugin offer are: the indirect diffuse inter-reflections, specular effects, dynamic geometry and lighting, reduces content creation time and is scalable. ("VXGI I GeForce", 2017)

3D meshes and environment

UE4 offers very basic possibilities for creating 3D meshes. The most common way to create the desired environment is to model all the meshes in a 3D modelling software (e.g. Autodesk 3DS Max, Maya, Blender) and further export the models into UE4 as FBX files. For this particular project, the same 3D scene that was used for creating the 360 renderings, was also used for exporting the meshes into UE4.

The chosen scene is an indoor space representing one of the offices from the Henning Larsen Architects (HLA) building. The 3D elements used in the scene are mostly furniture and accessories that are found in a regular office (desks, chairs, shelves, tables, etc.) and also different types of fixtures that are proposed for that particular space (Figure 3). At the same time, static human models were included to add a plus of realism to the scene. The original scene was developed to be used for high fidelity 3D renderings and because of this reason, the optimisation of the meshes was not required. When importing the scene in UE4, an optimisation process had to be used to simplify the meshes and make them usable in the engine, while maintaining the similar visual quality. The method utilised for this is decimation which represents a process through which the number of polygons of an object is reduced.

Further, all the required materials and textures were created in UE4, while keeping into consideration the reference renderings.

Interactivity

Creating the feeling of immersion for the user means that all their experience has to feel natural and intuitive. This means that the most basic and obvious interactions have to be taken into consideration when developing a platform in VR. First of all, the user should be able to feel that their actions have a direct effect on what is happening in the scene. The levels of interaction in the proposed prototype can be divided into two different categories:

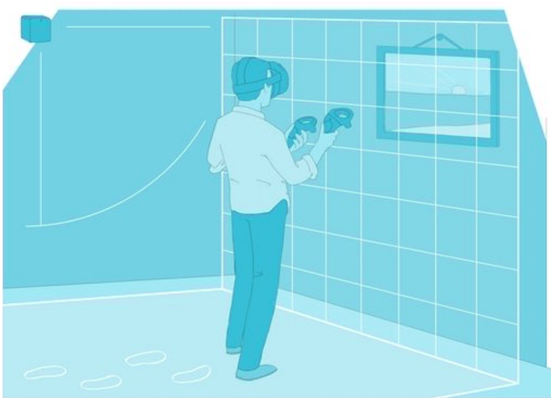

FIGURE 4: DELIMITATION O THE SPACE IN VR ACCORDING TO THE SIZE OF THE ROOM

- Movement and orientation
- Direct interaction with elements in the scene

Movement and orientation

This level of interaction describes the possibility of the user to move inside the space naturally. Having the VR equipment, the user can freely observe the area and gaze their attention in any desired direction. In the same time, the users can have a 360 degrees experience and also the feeling of depth for the environment. The infrared cameras that HTC Vive is delimits precisely the physical room so the user can physically walk and see the result that his character in the virtual world moving. This details that the current VR technology offers enhance the feeling of immersion for the users and can create a more realistic experience.

By having the possibility to move only in the space that the physical room is offering is a limitation for the possibility of exploring the virtual environment. In the current VR applications that are developed for HTC Vive or Oculus Rift, the developers use a method of “teleporting” the user from one point to the other in the virtual world. In this way, the user does not have to move physically and creates a feeling of safety (e.g. the user can hit different objects around him). (Figure 4).

This method is usually used in the current VR games and creates a more fast and engaging pace for the action games. This element doesn't create a realistic experience and is used more as a gamification feature.
In the presented prototype, the idea was that the user could actually explore the space, create the feeling that he is walking naturally, and at the same time to feel safe in the physical world. To achieve this, the movement was assigned to a classic game controller, that the users could use exactly as in a console game. This way of navigation was the most suitable, being clear and self explanatory.

Direct interaction with elements in the scene

The next level of interaction that the platform offers is with the lighting fixtures. In the scene, the user has the possibility to toggle between different types of fixtures, control the intensity, colour temperature or the light distribution. In the development process, the developer can add as many scenarios as he wants, and the user can quickly change between them using the game controller.

In the prototype that was created, the main source of light was the sunlight. The users had the possibility to control the position of the sun in the sky, different types of skylights, and the blinders of the windows. All those elements were intuitively accessible for the users, without the need for explanations. The prototype will be

FIGURE 5: SCENE IMPLEMENTED IN UE4. THE SAMPLE WAS USED AS A STARTING POINT FOR TESTING DIFFERENT LIGHTING SCHEMES

described with more details later in this paper.

After trying this platform, the results in term of lighting conditions inside of the scene were improved considerably but on the other had the frame rate has decreased exponentially. This is the last aspect that has to be taken into consideration for creating an engaging and immersive experience for the users. Based on the specifications for the VR head mounted displays a frame rate of at least 90 frames per second (FPS) have to be achieved so that the users won't have problems when trying the VR equipment.

First prototype

The first scenario that was analysed represents the third floor of the HLA building. This is an office area, with a large open space, and with a full glass wall on a side (Figure 5). The purpose of the scene was to showcase different possibilities for the artificial light that could be used inside the space. The 3D scene of the location and the renderings were obtained from another related project that is under development at AAU-CPH and further used as reference and starting point for creating the scene in UE4.

Regarding lighting, the scenario included four types of downlight fixtures, both hanging or fixed in the ceiling. Additionally, the users had the possibility to toggle between desk lamps and standing fixtures. The scenarios were programmed so that the user could make different combinations for lighting as it can be observed in figure 8.

For each type of fixture (Figure 6) was created a blueprint, which represents a pre-programmed instance of that particular fixture. Using this technique, the scene was optimised, and more convenient to be programmed. In UE4 each object that is placed inside the scene can have three different states: static, stationary and movable. To have interactive lighting fixtures, and to change different characteristics (intensity, visibility, colour temperature), the fixtures had to be set to movable, which means that the lighting couldn't be pre-calculated/baked. This requirement was necessary also for the global illumination plugin (GI). To have dynamic global illumination, the fixtures had to be movable, and the GI option had to be on because the plugin has the possibility to select only the desired fixtures to cast GI.

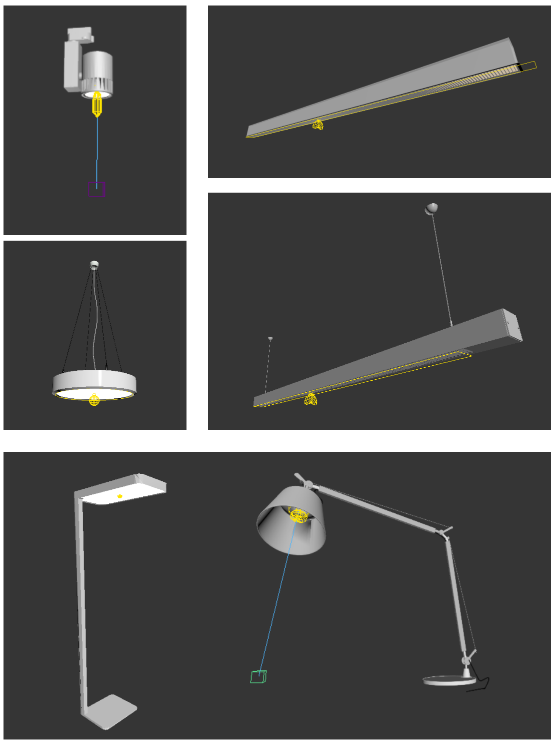

FIGURE 6: - 4 TYPES OF HANGING FIXTURES
- 2 TYPES OF STANDING FIXTURES

In UE4, the GI option can be obtained using a "post-processing volume" that can add different effects to the scene such as Anti-Aliasing, Bloom, Colour Grading, etc. (Figure 7). For the purpose of this project, only the GI effect offered by the VXGI plugin was used.

FIGURE 7: IMAGE SHOWCASING DIFFERENT EFFECTS THAT CAN BE MADE UTILISING THE POST PROCESSING VOLUME IN UE4

First prototype testing

In this case, a technical testing was conducted. The purpose of the test was to see if the created scene was meeting the requirements for working in VR and to check if the GI plugin is working correctly. The requirements for the test was to obtain 90 frames per second (FPS) while running the app in VR.

The first test was conducted on a scene without any light sources.(Figure 5). This was used as reference point for the following scenarios. In this test, the FPS was constantly 120FPS, so was suitable for VR. In the next scenario, each type of fixture was tested without the dynamic GI. In this case, the frame rate was constantly above 100 FPS. Similar results were also obtained during the interaction with the lights (turn on/off, change colour temperature, increase/decrease the intensity). In the final stage of the test, the dynamic GI was turned on, and the different types of fixtures were observed while interacting with them. (Figure 8) In this case, the FPS dropped considerably to a value of 45 while wearing the VR glasses. In this conditions, the scenario that the users would experience would be distractive and unpleasant with the possibility of creating dizziness or other motion sickness symptoms.

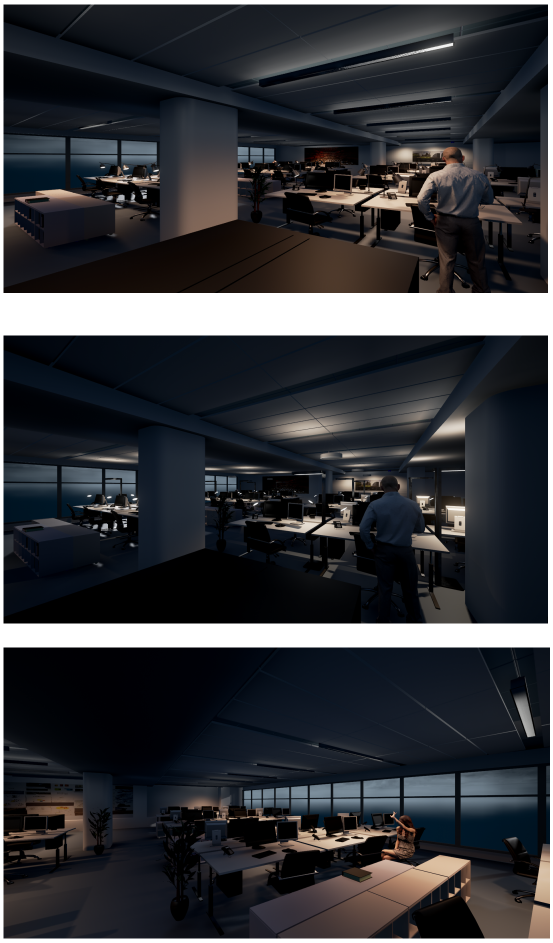

FIGURE 8: VISUALISATIONS FROM THE TESTING OF DIFFERENT TYPES OF

This massive drop in FPS was apparently created by the dynamic GI which was created using the VXGI plugin. Because of this, more detailed research was made in order to analyse how does the plugin affect the scenes and what can be improved in order to use some of its features while still having a pleasant experience for the users. Figure 9 represents the different types of lighting that were tested and how they affect the scene.

A similar test was conducted using a simplified version of the scene. In this case, a smaller office room was used, which didn't had any direct sun illumination. As can be seen if figure 9, the only source of light for this scene was the ceiling fixtures. The scene includes 8 light sources, and during the test they were turned on one by one in order to see how the performance is affected while adding multiple fixtures that cast dynamic GI into

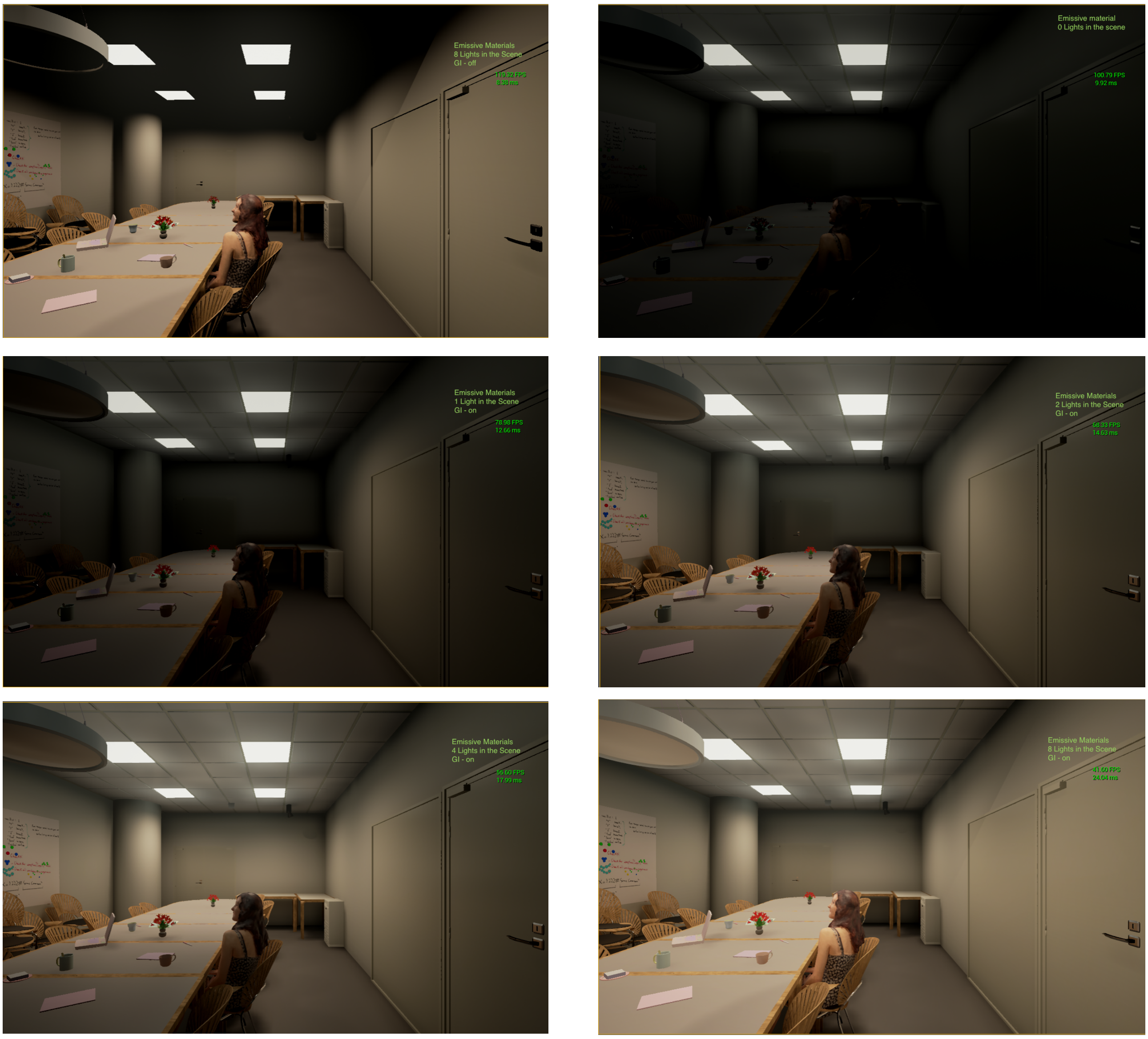

FIGURE 9: VISUALISATIONS THAT SHOWCASE HOW THE GI IS AFFECTING THE PERFORMANCE OF THE SYSTEM BASED ON THE NUMBER OF FIXTURES PRESENT IN THE SCENE ()ONLY THE GI FUNCTION WAS TURNED ON/OFF AND NOT THE ACTUAL INTENSITY OF LIGHT

	GI off	GI on
0 fixtures	120 FPS	100 FPS
1 fixture	120 FPS	80 FPS
2 fixtures	120 FPS	68 FPS
4 fixtures	120 FPS	55 FPS
8 fixtures	120 FPS	40 FPS

TABLE 1

the space. In table 1 it can be observed how the FPS was affected while the fixtures were turned on. Based on this test, it was observed that the FPS is decreasing proportionally to the number of fixtures that are added to the scene and each fixture affects the performance with approximately 12 FPS.

Another problem that was observed while using the dynamic GI in VR was that the image was not rendered correctly for both eyes. The user could see the correct image only in the left eye, while in the right eye the shadows are missing and the reflections on the materials were too bright.

Based on the observations that were made in this test, the plugin was not suitable to be used in a VR platform using artificial lighting for the indoor spaces. Similar results were also observed for other developers that tried the plugin in their projects, even if they were using higher specs computers. This can be found in one project developed by TCImage3D which showcase very low frame rate (15-20 FPS) in an interactive indoor scene while using top of the line graphics card (GTX Titan X). ("VXGI TEST FPS TITAN X", 2017)

Second prototype - Daylight

The following test was conducted in order to test how the daylight can be simulated in a VR scene. Similar with the previous test, the GI plugin was used in order to get a more rich and realising lighting for the indoor space. For this test, better expectations in terms of FPS were expected because the scene will include only one source of light which is infinitely far away from the scene. This means that all the shadows cast will be parallel, making the simulation to use less processing power.

To observe how the daylight is affecting the space, a day-night transition was created which is continuously looping through and in the same time offering the possibility to the user control the position of the sun to visualise any particular moment of the day.

Compared to the previous test, in this case, the models in the scene were optimised by reducing the numbers of polygons for each mesh, and further making the scene less heavy. This process was done using modifiers in 3DS Max that are specifically designed to optimise the meshes and in the same time to maintain the shape and materials.

As can be observed in figure 10, there are two sources through which the daylight can enter the space. The first one is represented by the standard windows which fill the left side of the room completely. As a level of interaction, the users can control the position of the

FIGURE 10: VISUALISATION OF THE FINAL DESIGN INCLUDING THE LIGHT SOURCES AND ALL THE UTILISED ASSETS

blinders (Figure 11) which will further affect how the daylight enters the space.

The second source of light is the two skylights that are positioned in the middle of the room. The users have the possibility to chose between four different types, each of them influencing how the light is coming into the space differently. The choices for the skylight are as following: - large skylight, three meters wide (Figure 12A); - two small skylights, each one meter wide (Figure 12B); - medium skylight, two meters wide (Figure 12C); - Japanese wood grid, can be toggled on/off for each of the previous choices (Figure 12).

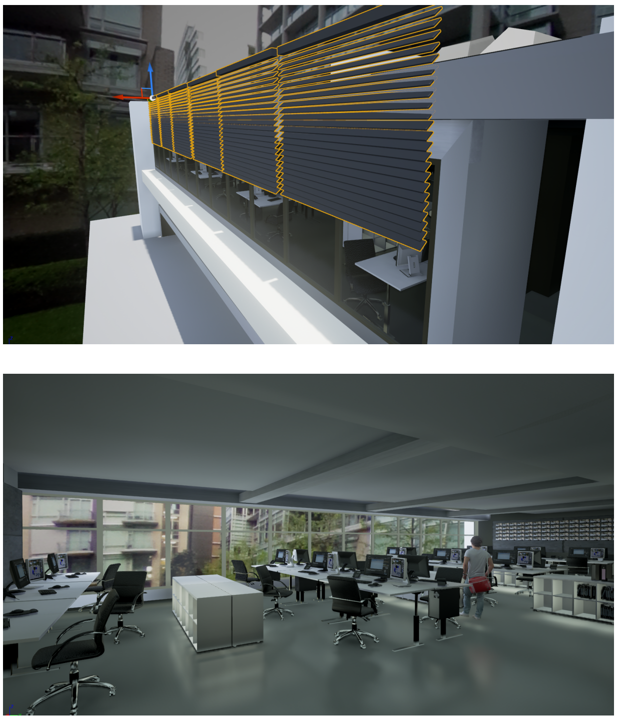

FIGURE 11

To add more realism to the scene, a sky sphere with an HDRI image was used (Figure 10). The daylight was programmed using blueprints and was set up according to the position of the buildings that can be seen in the HDRI image to get a more realistic simulation. (Appendix A)

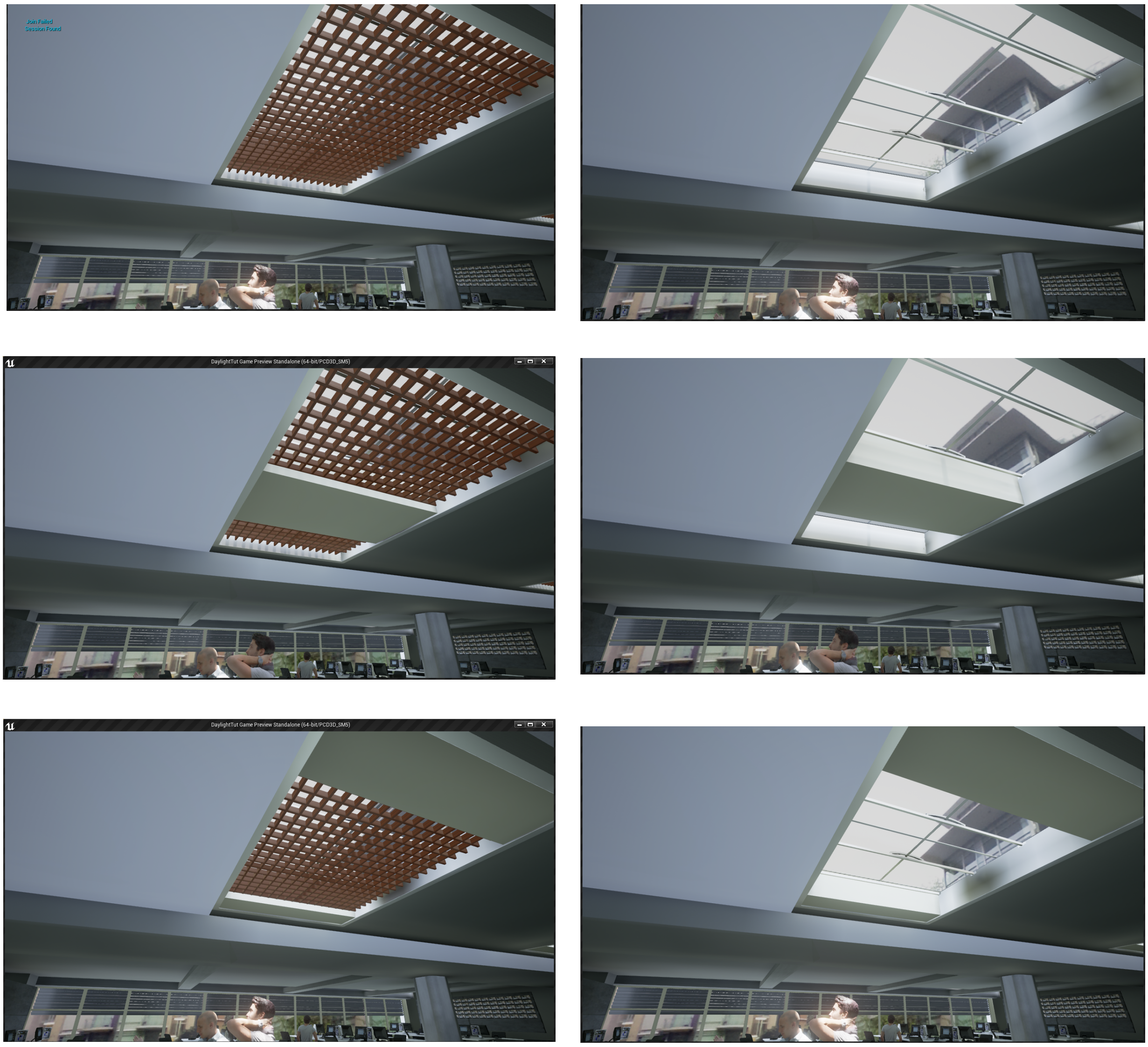

FIGURE 12: - DIFFERENT VARIATIONS FOR THE SKYLIGHT:
A - LARGE SKYLIGHT WITH/WITHOUT WOOD GRID (FIRST ROW)
B - 2 SMALL SKYLIGHTS WITH/ WITHOUT WOOD GRID (SECOND ROW)
C - MEDIUM SKYLIGHT WITH/WITHOUT WOOD GRID (THIRD ROW)

Interactivity and multiple users functionality

The vision of the prototype was that the lighting designer could present its idea to the clients in a more flexible and easy to access way. The client doesn't have to be physically present in the same room with the designer when he observes the simulations, and they can meet in the virtual environment from anywhere in the world. To achieve this, a networking functionality had to be implemented so that multiple users can experience the space at the same time while the lighting designer can guide them through the space.

This functionality was achieved using the Steam APIs that are included in UE4 through plugins. The designer can create separate lobbies that can support up to 8 users. In the same time, Steam offers another functionality that can handle the communication between the users. To add a plus of realism to the simulation, virtual avatars were created to create the feeling of presence in the space. This level of gamification is necessary for the scene, and it adds value to the degree of immersion for the users.

The users have the possibility to use the platform in a local connection (LAN) or remotely via an Internet connection. At the same time, all the interaction with the environment is synchronised for all the users, so any action is affecting the experience of all the participants in the simulation. The multiplayer functionality has been developed and tested as a separate project. It represents an important layer of the final platform, but for the purpose of this research, it hasn't been included in the prototype.

360 Renderings - Samsung VR

In order to assess the functionality and the usability of the prototype a second system was implemented. Further, a comparison test was conducted and the results were analysed based on the comparison of the two systems.

As was previously mentioned, 360 static visualisations represent another feasible way of presenting different concepts to the clients. The VR headset can be calibrated to render those images offering the users the possibility to observe the space surrounding them, but from a fixed point. This idea was created as a second system and for this was used the Samsung Gear VR headset that helps to visualise VR content on a mobile phone. All the content presented was created using the V-Ray engine and 3DS Max and further rendered in VR using the 360Photos application offered by Samsung. A total of six renderings were created (Appendix B), simulating the different types of skylight that could be also accessed in the main prototype. The renderings simulates the office during the daytime, in order to observe how the light affects the space. The content was created in order to have consistent and relevant data for the test.

Testing

The purpose of the test was to compare the two technologies regarding experience, usability and accessibility for the lighting designers. The task of the participants was to try each sample for one minute, and after each session, they had to answer to a survey.

Testing Setup

The testing session took place in the first week of May at Aalborg University Copenhagen. The setup was placed in a public area of the university to have a larger space for the users to move and at the same time to create a welcoming environment for the potential participants.

The setup of the first prototype consists of a desktop computer which runs the necessary software and the HTC Vive HMD. The users had an area of six square meters to move, and this area was also limited in the virtual space using “fake walls” to keep the users safe from the surrounding objects. The second testing sample consists only of the Samsung smartphone and the head mounting support, without any other add-ons. The testing sessions were video recorded for further analysis, and a separate laptop was used for assessing the surveys. Each test

Basic Statistics

	Minimum	Maximum	Median	Mean	Standard Deviation
	23.00	34.00	27.00	27.87	3.86

TABLE 1

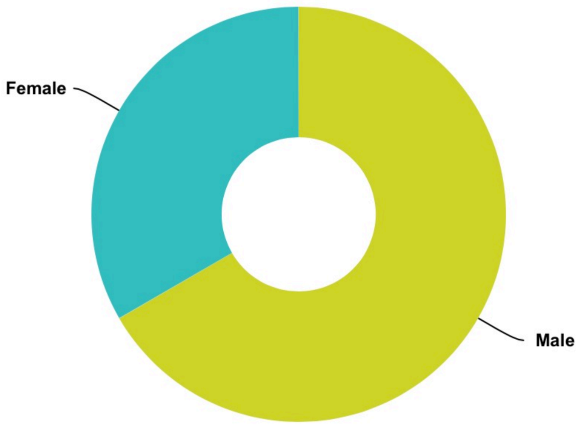

CHART 1

was approximately 15 minutes long, consisting in the explanation of how the systems work, the actual test and the answers to the surveys.(Figure 13)

FIGURE 13:

Testing participants

To have conclusive results, the target group for the test was narrow down to lighting design students in the first or second year of study. These limitations were made to have consistent answers from experienced users which know what the requirements and needs in this profession are. In total 15 participants were assessed, both males (67%) and females (33%) (Chart 1) with ages varying from 24 to 34 years old (Table 1).

Test description

As a testing method, the A/B test was used to compare the two versions of the software and to determine which one is considered more suitable for the users. The A/B test is essentially an experiment in which one or more variants of a prototype are compared with the control version. The samples are shown to the users at random, and statistical analysis is used to determine which variation performs better for a given conventional goal

At the beginning of the test, the participants were introduced to the following theoretical situation:

“Imagine that you are a professional lighting designer and a client comes with a project in which he needs to change the design of an office in such a way that more sunlight can enter the room during the

daytime. After you come up with few concepts, you have to meet the client and present your ideas to convince him. Instead of rendering different images with your suggestions, you choose to present your idea in a more interactive way.”

After the participants had been introduced to the scenario, they had to test the two systems. To have conclusive results and to avoid having the test biased, half of the participants tried the experiment with HTC Vive first (interactive environment), while the other half tried first the Samsung VR (static 360 visualisations). Following this routine, the requirements for having an A/B test are achieved which makes the analysis of the results to be statistically significant.

After each session, a set of 9 questions were asked to assess their experience with that particular system. At the end of the test, another survey was used to compare the two systems in different real life situations. (Appendix C) The questions and the results will be analysed and presented in more detail in the following pages.

Results

After the testing session had been conducted, the results of the surveys were gathered through the system offered by the platform SurveyMonkey.com. The responses were further divided based on the category in which each participant belong to (based on which version of the software they tried first) and further tested from both qualitative and quantitative perspective. In the end, the results were compared to see if the answers were consistent and finally used for assessing the initial problem statement. All these steps will be further presented in this chapter.

First category

This particular category is represented by the participants that first tried the prototype with the dynamic environment (HTC Vive) and secondly the static 360 visualisations (Samsung VR).

Dynamic environment (HTC Vive)

Based on the responses the users had a good understanding of the idea of the prototype without having difficulties in relating it to the scenario to which they were introduced. As can be seen in Table 2 the answers are all the higher part of the scale.

Not at all	(no label)	(no label)	(no label)	Completely understand	Total	Weighted Average
0.00% 0	0.00% 0	12.50% 1	25.00% 2	62.50% 5	100.00% 8	4.50

TABLE 2

When the participants were asked to assess the applicability of the prototype in different kind of situations than the one that was presented in the test, their answers were mostly positive, with the majority of the answers in the higher part of the scale. (Table 3)

Not Useful	(no label)	Useful	(no label)	Very useful	Total	Weighted Average
0.00% 0	12.50% 1	0.00% 0	50.00% 4	37.50% 3	100.00% 8	4.13

TABLE 3

Regarding the visual quality of the content that was presented, a higher variety of the answers was observed while having the majority of the answers with 5 out of 5 points (Higher is better). Also for this particular question, the weighted average of the responses was 4.13 out of 5, situating in the higher side of the scale. (Table 4)

1	2	3	4	5	Total	Weighted Average
0.00% 0	12.50% 1	12.50% 1	25.00% 2	50.00% 4	100.00% 8	4.13

TABLE 4

Regarding interaction and usability, the majority of the answers were situated in the middle of the scale, suggesting that the controls for interacting with the prototype can be easily understood, but at the same time they may not be the best option for this particular system. The average results rate was 3.38 out of 5 (Higher is better). At the same time, some participants suggested other ways of controlling the system instead of using a joystick. Some of the suggestions were: "Google Daydream", "Vive Motion Controllers", "Leap Motion". This feedback will be taken into consideration as further development of the prototype. (Table 5)

Very hard	Hard	Moderate	Easy	Very easy	Total	Weighted Average
0.00% 0	0.00% 0	62.50% 5	37.50% 3	0.00% 0	100.00% 8	3.38

TABLE 5

Based on the results, the participants appreciate in the prototype the level of immersion, the interactivity and the possibility of exploration. In the same time, they saw the possibility of testing different design ideas and the use of the platform as a tool for presenting to the clients the created content.

Some of the participants mentioned a problem with the functionality of the blinders in the scene. They considered that the daylight is not affected properly by their movement. This is a known problem which will be described in the further chapters and at the same time evaluated for the further development of the platform.

Regarding experience, the participants describe it as *"amusing", "attractive", "good"*, and they consider the platform as a "*helpful tool for future visualisations"*. Using the VR technology, one of the participants mentioned that "*in 10 minutes of VR, you can explain more than 30 minutes standard presentation*".

When they were asked what they considered that was missing from their experience they mentioned that the necessary functionality was present. One of the answers suggested that statistics related to lighting ("where is the north located, the cost of implementation, daylight factor, luminance and illuminance, time and date *for the sun position*, how can artificial light compensate some areas") should be presented.

Static 360 visualisations (Samsung VR)

Based on the responses, in this case, the participants had a good understanding of the prototype again. The majority of the answers were on the higher side of the scale, with an average of 4.38 out of 5 (Table 6).

Not at all	(no label)	(no label)	(no label)	Completely understand	Total	Weighted Average
0.00% 0	0.00% 0	12.50% 1	37.50% 3	50.00% 4	100.00% 8	4.38

TABLE 6

When they were asked if they can imagine the system being used in other similar situations then the one that was described in the test the answers were divided, with three responses on the lower side of the scale and five above the average. (Table 7)

Not Useful	(no label)	Useful	(no label)	Very useful	Total	Weighted Average
0.00% 0	37.50% 3	0.00% 0	37.50% 3	25.00% 2	100.00% 8	3.50

TABLE 7

Regarding the quality of the visualised content, the answers were again divided. Half of the participants didn't consider that the quality was good enough while the other half find it acceptable. The average of the answers was 3.25 to of 5 which can also be seen in Table 8.

1	2	3	4	5	Total	Weighted Average
0.00% 0	50.00% 4	0.00% 0	25.00% 2	25.00% 2	100.00% 8	3.25

TABLE 8

Regarding usability and interactivity with the system, the majority of the users consider it as very easy to use. Five participants rated it as very easy to use while the other three as medium difficulty. The average of the answers was 4.13 as it can be seen in Table 9.

Very hard	Hard	Moderate	Easy	Very easy	Total	Weighted Average
0.00% 0	12.50% 1	25.00% 2	0.00% 0	62.50% 5	100.00% 8	4.13

TABLE 9

Based on their feedback it was observed that the answers of the participants were closely related to their previous experience with the dynamic scenario. They consider the experience not as immersive and describe that understanding the concept cannot comprehend that quickly.

The participants appreciated the image quality and the simple experience, and consider that the limited choices make it easier to focus on actually visualising the designs. One participant mentioned that "*after looking at the other one, this seems like really bad. But if you have never seen the other one, then this is a good experience. That it's simple is really good for people that there might not be technical smart*".

The participant, in general, considered the experience with the Samsung VR as being more simple and easier to control than the one with HTC Vive. They find it as an attractive alternative for the other headset especially because of its portability, but regarding the visualised content and possibilities of exploring the space, they consider it weak compared to the other alternative.

Other scenarios

In the final part of the survey, the participants were asked to evaluate six different environments in which the presented technologies could be applied and to decide which one would be more suitable. The scenarios were selected to cover a larger variety of situations, both indoor and outdoor. The following scenarios were tested, and the graphics describe the reference of the users in each case.

Lighting Design for supermarkets.

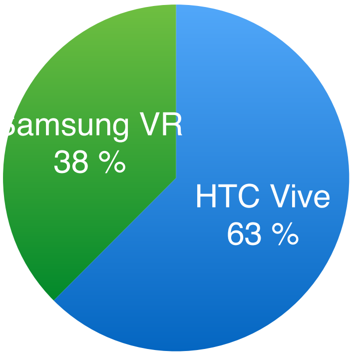

CHART 2

The participants, in general, consider that the dynamic presentation of the space can offer more information to the client and the designer itself, and the possibility to adjust different specifications in realtime can be an advantage. In the same time, they consider that also the representation of the scenes using static renderings can be useful, but this depends on the complexity of the projects and the requirements of the clients.

Lighting Design for Gas Stations

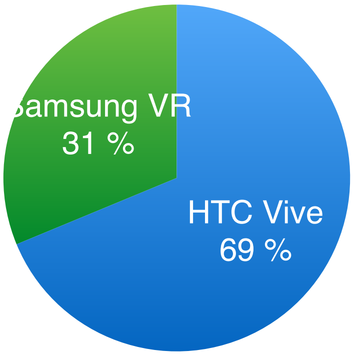

CHART 3

Similar answers were also gathered from this situation, and some participants mentioned that having an outdoor scene, the effect of daylight is more important so a dynamic space would be more suitable.

Interior Lighting Design

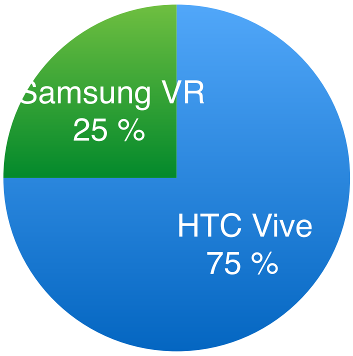

CHART 4

Similar answers as for the other situations with some of the participants pointing out the better quality and the experience offered by the dynamic system (HTC Vive). In the same time, they mentioned that providing to the clients the possibility to experience the actual space creates more trust and a bigger chance to make them invest in that idea.

Lighting Design for Classroom

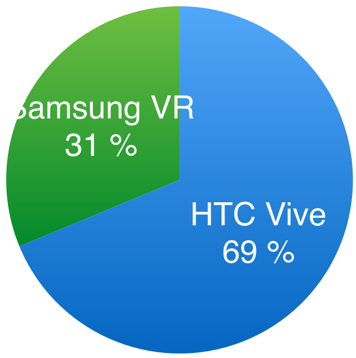

CHART 5

In this case, the participants still consider the dynamic environment more suitable but in the same time they pointed few situations in which the static 360 renderings could be more suitable. Having a smaller space with activities that are happening mostly in a static position (students in sitting position, teachers in front of the class) the static 360 visualisations can offer a good understanding of how the actual design would look and can make the clients understand what experience they would obtain.

Street lighting

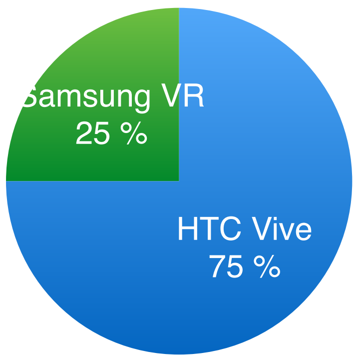

CHART 6

Similar answers were obtained for this case, with some of the participants considering that based on the level of investment and implementation, a more detailed presentation of the actual concept is needed. They also consider that having a larger space, the possibility to explore is a necessity.

Facade lighting

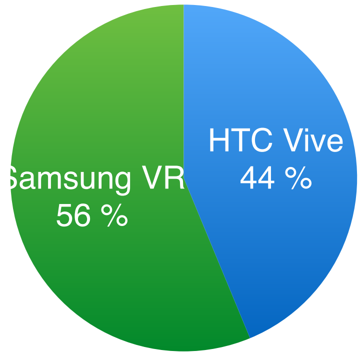

CHART 7

Compared to the other scenarios, in this case, the results were for the static 360 visualisations. In general, the participants considered that the movement is not a critical aspect, while the pedestrians and the other users of the space will experience the lighting design only from one perspective. One participant mentioned that creating visualisations from different points of view can easily present the overall idea.

Each scenario was portrayed as a visualisation which can be seen in Appendix C.

Second category

This particular category is represented by the participants that first tried the prototype with the static 360 visualisations (Samsung VR)and secondly the dynamic environment (HTC Vive).

Static 360 visualisations (Samsung VR)

When the participants were asked how well they understood the concept of the prototype and how is related with the scenario to which they were introduced, the answers were positive, with the majority obtaining 5 out of 5 points. The average of the responses was 4.71 out o 5 (higher is better). (Table 10)

Not at all	(ingen etiket)	(ingen etiket)	(ingen etiket)	Completely understand	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	0,00% 0	28,57% 2	71,43% 5	100,00% 7	4,71

TABLE 10

The participants considered the platform as being useful for their working process, having all the answers above the "useful" level. The weighted average of the answers was 3.71 (Table 11).

Not Useful	(ingen etiket)	Useful	(ingen etiket)	Very useful	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	42,86% 3	42,86% 3	14,29% 1	100,00% 7	3,71

TABLE 11

Regarding quality of the visual content, all the answers were situated in close to the middle of the scale and having a weighted average of 3.71. (Table 12)

1	2	3	4	5	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	28,57% 2	71,43% 5	0,00% 0	100,00% 7	3,71

TABLE 12

Regarding usability and interactivity with the system, all the received answers were above the average, being evenly distributed between moderate, natural and very easy to use. The average of the responses was 4.14 as it can be seen in table 13.

Very hard	Hard	Moderate	Easy	Very easy	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	28,57% 2	28,57% 2	42,86% 3	100,00% 7	4,14

TABLE 13

In general, the opinion of the participants suggests that they had an enjoyable experience using this particular system, and they consider it as a straightforward and intuitive way to show your designs to the users and clients. They describe it as a useful tool for connecting the concept of working with different types of lights, to the actual context. One participant considers it as a "good way to evaluated receive users opinion before the actual design and implementation".

Some of the participants mentioned as a disadvantage the feeling of dizziness and the need of "ground under their feet". They mentioned that because of the lower resolution of the headset, the focus from observing the actual content was distracted.

When the participants were asked to describe their experience, they consider it as "convenient" and "fun" especially because of the simplicity and the immersion that was offered. At the same time, one participant mentioned that the experience was "*ok, but I would still prefer images*".

When they were asked what other functionality they would prefer to have, they mentioned the possibility to "walk inside of the office", "observe from different spots in the office" and more interactivity with the lighting elements. Some of the participants mentioned that they were expecting "more inferences between the scenarios" and more smooth transitions between the samples (animation/time-lapse).

Dynamic environment (HTC Vive)

Based on the responses, the participants had a good understanding of the idea and the concept of the prototype. The majority o the answers for this case received 5 out of 5 points, with a weighted average of 4.86 out of 5 (higher is better).(Table 14)

Not at all	(ingen etiket)	(ingen etiket)	(ingen etiket)	Completely understand	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	0,00% 0	14,29% 1	85,71% 6	100,00% 7	4,86

TABLE 14

When they were asked if they would consider the prototype useful also for other situations than the described one, the majority of the participants consider it as "very useful", having an weighted average of 4.86 out of 5. (Table 15)

Not Useful	(ingen etiket)	Useful	(ingen etiket)	Very useful	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	0,00% 0	14,29% 1	85,71% 6	100,00% 7	4,86

TABLE 15

Regarding the visualised content, the answers were again on the higher side o the scale, having the majority of the answers with maximum score. The weighted average in this case was 4.71 out of 5. (Table 16)

1	2	3	4	5	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	0,00% 0	28,57% 2	71,43% 5	100,00% 7	4,71

TABLE 16

By assessing the usability and the method of interaction with the platform, the results suggest that the participants didn't have any problem in understanding the functionality and they consider it "easy" or "very easy". The weighted average of the answers in this case was 4.43 out of 5. (Table 17)

Very hard	Hard	Moderate	Easy	Very easy	I alt	Vægtet gennemsnit
0,00% 0	0,00% 0	0,00% 0	57,14% 4	42,86% 3	100,00% 7	4,43

TABLE 17

Based on the participant's feedback, it can be mentioned that they didn't have difficulties in understanding the concept. In general, they appreciate the possibility to move around the space while also having the opportunity to interact with the different elements. Having the option to manually control the direction of the daylight is considered as a useful tool for understanding and experiencing how the light affects the room. Many of the responses were made as a comparison with the previously tested system, while the participants tried to point out some of the advantages such as the possibility to navigate, interact or see the scene from different perspectives.

In terms o level of interactivity, some participants had different opinions. Some answers suggested that the prototype may have "too many options to choose between", which may not be too user-friendly for presenting the ideas to a client that may not have the necessary technical experience. On the other hand, some participants suggested that a more complex scene that has more options to choose from can be more valuable.

When they were asked what kind of improvements they would suggest, they pointed the possibility of actually walking inside the space instead of using the controller. At the same time, the participants asked for the functionality of simulating the interaction with different objects in the scene such as the chairs (sit on them/ move them around), interaction with the computers, etc.

Other scenarios

Lighting Design for supermarkets

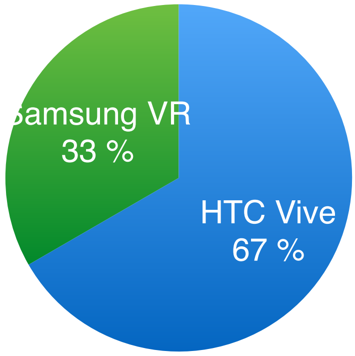

CHART 8

In general, the participants considered the simulation of a dynamic environment as being more suitable for this situation. This choice was made mainly because of the possibility of exploring the space which can give "a better sense o the place". The interactivity with the lights was described as unnecessary because, in this type of location, the users of the space won't have to use it.

Lighting Design for gas station

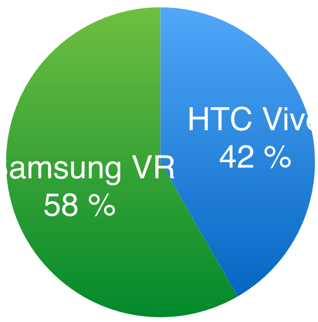

CHART 9

In this particular case, the participants considered that the exploration of the space is not necessary. The lighting of this particular location can be observed from afar (e.g. from the street) or from the perspective of the clients that are refuelling their cars. Because of this, the static 360 visualisations can me more than enough for presenting the concept.

Interior Lighting Design

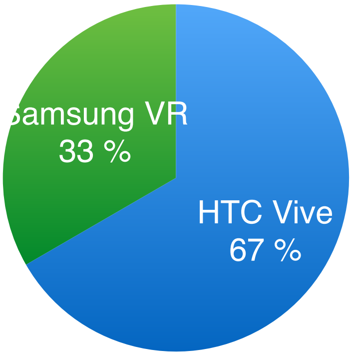

CHART 10

In the scenario of interior design, the participants considered that the possibility to explore “your future home” and the interactivity with the different light sources is an important aspect. One participant described that both systems could be used in this case, using the 360 visualisations for prototyping in the early stages of the project and the dynamic environment as a final presentation for the client.

Lighting Design for classroom

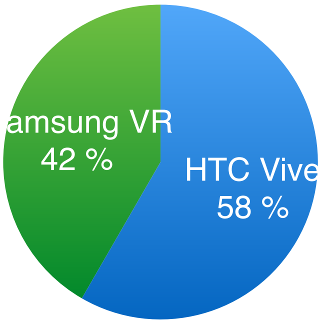

CHART 11

When the participants were asked to explain their choice, they mentioned that the users of the space would have mostly a static position during a lecture so the static visualisations would be enough to present this experience. Even though, the majority o the participants preferred the dynamic environment because of its possibility to present interactively different lighting scenarios.

Street lighting

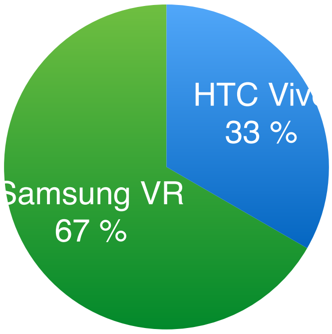

CHART 12

IIn this situation, the participants described that the street lighting is usually repetitive and uniform along the street. Because of this, different renderings from the perspective of various users of the space (drivers, pedestrians, bikers) Amy be enough to have an understanding of the space and the design.

Facade lighting

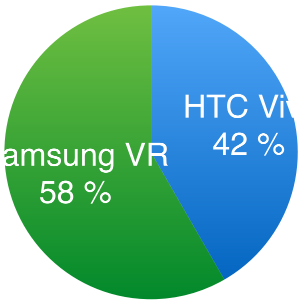

CHART 13

In this case, the participants considered that the size o the building plays a significant role in choosing the system. If it is a bigger building, the design has to be observed from a distance, and static visualisation can be used for this. In the case that also the lighting design is static the Samsung VR can be the necessary tool, but in the situations that the lighting is interactive, the participants mentioned that the dynamic element is needed.

In the following chapter, the theoretical framework and the results from the testing session will be analysed and concluded.

Discussion

The primary purpose of this research paper was to analyse how a lighting designer can find the use of a technological tool that is presenting real-time rendered content in VR. In order to analyse this topic, the following problem statement was formulated:

"Offering the freedom to the users to explore a virtual space in real-time instead of presenting it using static 360° renderings can enhance the immersion and can provide a closer to reality way to present the lighting solutions to their clients."

As previously mentioned, to answer the problem statement, the following research was formulated and analysed from a theoretical and practical perspective:

1. To which extent the user can manipulate the lighting in VR to maintain accurate/close to real life lighting designs?
2. In which scenarios/situations the freedom of exploring the VR space is more beneficial?

Based on the previous studies and the related work, it can be considered that VR technology became nowadays one of the most advanced and powerful tools that a designer could use to present his creations. Using the virtual space, the content can be accessible, easy to understand, and also cost efficient.

For a new technology to be accepted as useful and reliable, it has to bring new elements helpful for the designer or to enhance the existing functionality. In the case of VR, this technology brings the possibility of visualising the created content in a new way. Having the freedom to observe the concept in the virtual world, exactly how you would see it in real life can help in understanding it, and visualise the outcome, without actually creating a real demonstration.

The VR technology tries to create an immersive experience for its users, but to achieve the feeling of full immersion in a virtual simulation, all the human senses should be involved. Using the headsets, only visual stimuli are included which can represent a limitation.

Having the possibility to explore the virtual space can represent an extra layer in achieving the feeling of immersion and further the sense of realism in the scene.

By designing the prototype that was presented in this research, I have tried to observe and analyse how far the current technology permits us to go, to achieve a simulation that is close to reality, focusing mainly on the lighting elements.

Based on the research and on the technical tests that were conducted, one o the most problematic part that had to be analysed was the indirect lighting of the space. In real life, all the light beams emitted into a space by a source of light is further reflected by the objects reached in its way. To achieve more realistic lighting in the virtual environment, a similar process has to be utilised. Rendering engines use algorithms for global illumination to achieve this effect, but typically this process requires a long time for each frame.
In the case of real-time visualisation of the space in VR, the indirect lighting has to be calculated almost instantly, to maintain a good experience or the users.

The conducted tests suggest that the real-time global illumination can be implemented in a VR application only to some extent. Having a complex scene, with many light sources can decrease the performance of the system and affect the VR experience. The first tests were conducted utilising indoor lighting, and the results suggest that the real-time GI is not suitable for this particular case. This case can be applied only on a smaller scale, utilising one or two fixtures in the scene. This kind of test can be conducted for observing how one fixture affects the space and not on a larger or final prototype. Even though, the software offered by Nvidia can be a starting point, and, in time, while the technology will evolve, the tool can become completely usable for any particular situation.

The second test conducted was made utilising only the direct light from the simulated sun. In this case, the scene includes only one source of light, which makes the process of calculating the indirect lighting to utilise less processing power than in the previous cases. By using only this type of light, and by optimising the quality of the meshes in the scene, the results were satisfactory.

After achieving the desired lighting different elements of interactivity could be implemented. Working with daylight means that the control over the position of the sun is an important aspect. In this way o thinking, offering the possibility to the users to change its position can help them understand how it affects the space in any desired period of the day.

The second level of interaction that was implemented was with the blinders and the different types o skylights. These elements were added to the scene to give the users more options and variations for the designs. In the same time, this layer can make the users understand what are the possibilities of such a technology and can help them to become more creative if they would have to use the tool in some o their future projects.

The last option available in the platform is the possibility of having multiple users in the scene. This functionality can add value to the collaboration that takes place during the design process and can help the designers to cooperate to achieve their desired goal.

Based on the final test that was conducted, it can be concluded that the dynamic simulation had a positive impact on participants. Based on their feedback, they seem to understand what are the benefits of using such a technology and they pointed some of the advantages that I have tried to achieve during the design process.
After analysing the results of each category from the test, it was observed that in general, the test with the dynamic environment which was made utilising the HTC Vive headset, obtained better results in each category compared with the static 360 visualisations (SamsungVR). By analysing the results from both testing sessions, for each device separately it could be observed that the results are slightly different. In the case when the HTC Vive headset was tested as the second option, the participants tend to appreciate the experience with higher grades (Chart 14), while for the SamsungVR, the exact opposite results were obtained (Chart 15). The reason for this difference in results can be considered as being the fact that the participants were comparing the two experiences from the testing sessions.

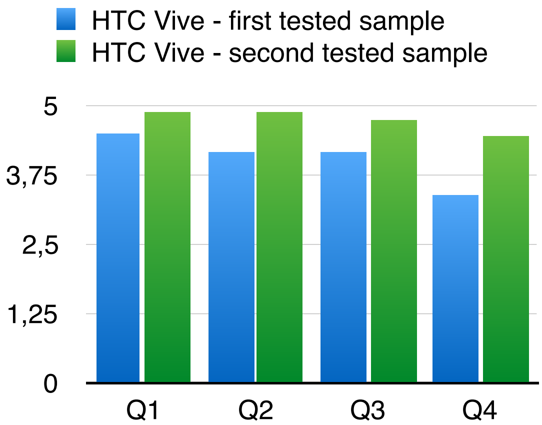

CHART 14

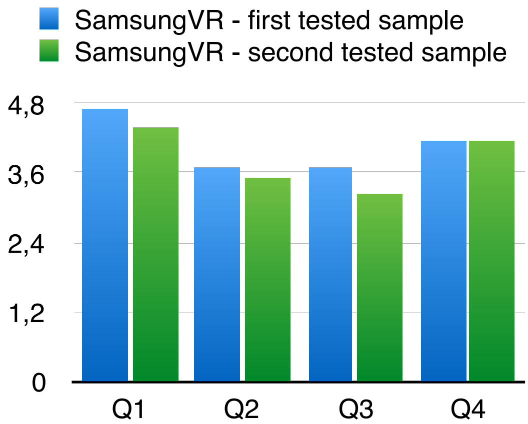

CHART 15

Based on the quantitative measurements, it can be mentioned that the participants tend to appreciate more the elements and the experience offered by the dynamic VR experience while they compare it with other technology.

To have final results for the A/B test, the answers from the two categories were combined, and the final results can be seen in Chart 16.

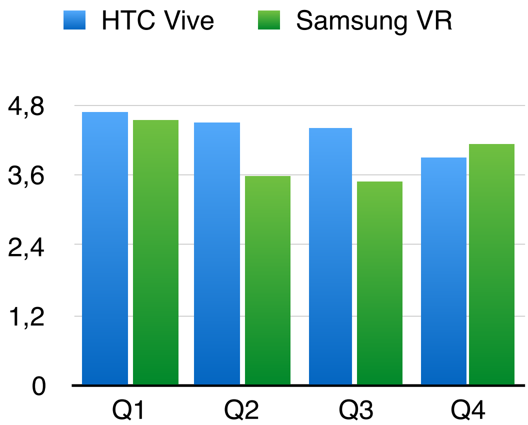

CHART 16

The results show that for both systems the users understood the concept and the idea that was presented (Q1) By introducing the participants to the scenario before actually trying the prototypes, helped them to understand the simulation.

The bigger differences in the two systems can be seen in the results from the questions related to usability of the application in different situations (Q2) and the quality of the visualised content (Q3).

In those two cases, the participants appreciated more the image quality offered by HTC Vive headset in combination with the dynamic simulation and at the same time the level of interactivity provided by this system. The quality and the resolution of the images in VR can affect the immersion and the experience of the users considerably. In the same time, having the possibility to explore the space and to visualise the elements from different perspectives, without having any interruptions, can add value to the project and this can also be seen in the results of the test.

Regarding usability, the participants saw the possibility of the system to adapt to different scenarios, while maintaining the same level of immersion and interactivity.
The last question that was observed in the test was related to the controls of the two platforms, and how user-friendly they are. In this case, the SamsungVR obtained slightly better results due to its simplicity. The users didn't need any explanation to interact with the system while for the HTC Vive, the users suggested that the user interface could be made more intuitive. Based on the results having the controls on a gaming controller can be disturbing. In this case, more natural ways of controlling the scenes can be implemented, but this will be further discussed in the following chapter of the paper.

Based on the feedback of the participants, the proposed system has potential to be used by lighting designers in their working process. The users appreciated the possibility of interaction which makes the simulation more engaging and creative.

The possibility of moving inside the space was considered a necessity because it can offer a better understanding of the space and it increase the level of immersion in the virtual simulation.

At the same time, the participants mentioned some of the problems that they encounter during the testing, and mostly all of them were related to the way that the direct sunlight is affecting the space. The transition between open and closed blinders didn't affect correctly the light that was coming into the area. This problem was encounter because of the GI plugin which didn't work as expected for this particular case. This issue will be further investigated, and more research will be done.

Based on the results from assessing different indoor and outdoor situations it can be concluded that the participants preferred the dynamic VR simulation in mostly all the cases. The reasoning of their choices was related to the necessity of exploring that particular space to have a better understanding of what the actual users of the space will experience. In the case of a large location such as a supermarket, the lighting designers have to showcase how the clients of the shop will experience the space while walking in different areas. The same principle can also be pointed in the case of an apartment, where the potential buyer wants to see how his future home will look and feel.

Positive answers were also gathered for the static 360 visualisations which could be useful for simulating large outdoor lighting designs (facades, bridges, monuments) or indoor spaces where the movement of the users in the space is not the primary requirement (classrooms, hospital labs, offices). At the same time, this simulation can also be made dynamically, but the required extra work may be not necessary.

The results gathered for this test, in general, suggest that a dynamic simulation which interactively presents different lighting scenarios is useful for a lighting designer. With the current technology, the workflow is limited at utilising more simple scenes, but the results may be promising. If the correct and calibrated light is obtained, the possibilities of interaction with it are limited only by the imagination of the designer and the requirements for that particular project.
The research suggests that the prototype can be applied to any particular scenario, but at the same time it has to be considered if the extra work for creating all the interactive elements is required.

Conclusion

Taking into consideration the research made and the acquired results from the testing sessions it can be concluded that the suggested prototype can represent a valid tool for lighting designers.

By having in mind the proposed research questions, it can be mentioned that the interactive elements that can be found in the simulation add value to it by creating a more engaging experience for the users. In combination with the immersion offered by the VR technology the prototype a virtual space where the lighting designers can showcase their ideas to the clients in a more clear and understanding way.

By answering the two research questions, it can be concluded that the problem statement has a positive result. The proposed prototype offers the possibility to the users to explore the virtual simulation of a particular location and in the same time to interact with different relevant elements. Based on the results of the testing sessions, it was proved that the feeling of immersion was increased compared to the static 360 renderings while at the same time simulating the lighting conditions similar to real life.

Based on this, I consider that the proposed prototype fulfils the requirements and needs of a lighting designer and can represent a starting point in the use of VR and real-time simulations for presenting and designing different lighting concepts.

One of the disadvantages of the proposed prototype is the limitation of the current technology. The indirect lighting is one of the most important aspects of analysing how the light affects the space and in the working process of a lighting designer it has to be precise and correctly simulated. As was previously described, the real-time GI can be used nowadays only to some extent. Because of this reason, it cannot be concluded that the proposed prototype represents a complete tool, but it can be taken into consideration for the future development.

Further development

Based on the feedback an important improvement to the prototype is to offer to the users different relevant information related to the elements of the scene. In the presented simulation, information about what is the exact hour at a particular position of the sun would be necessary, having different types of the sky (clear sky, overcast, etc.) or even information about each type of skylight (size, materials, design, etc.).

Secondly, research has to be made concerning the controlling device. In the current version, based on the results, the prototype didn't have the most intuitive controlling system, and some suggestions were made by the participants who will be taken into consideration.

Another important step in the development process is to test the prototype with a different gaming engine such as Unity3D. This step is important to analyse how other software is using the lighting features and possibly to improve current conditions.

Because the VR technology is in its early stages, the possibilities for achieving a complete tool are also limited. Even though the developers managed to create impressive applications that use it, and the realism of the content starts to be more and more impressive.

Currently, I consider that the prototype that was proposed for this research can be useful for presenting simulations in schools for educational purposes and hopefully, in time, it can extend and become a reliable tool also for professionals.

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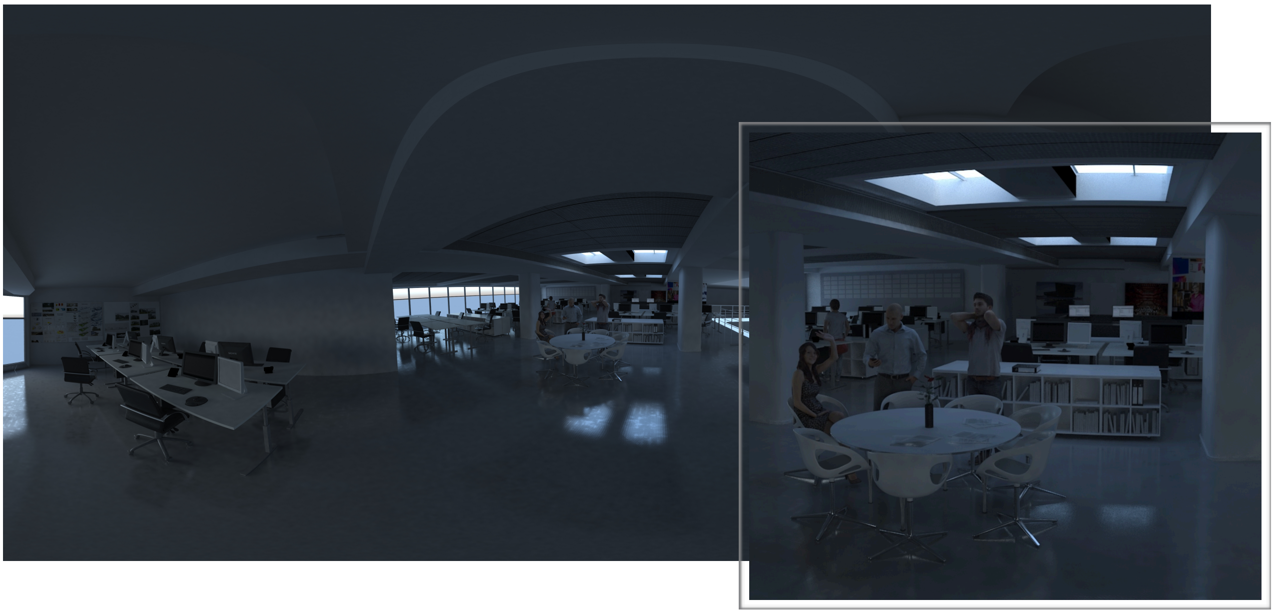
Appendix A

Visualisations representing the final outcome of the project. In the following images it can be observed how the dynamic daylight enters the space. The interactive elements will be showcased in the video production that is attached to the project.

Appendix B

Visualisations utilised for presenting variations of skylights. The samples were rendered in 360-degrees utilising V-Ray and further presented to the testing participants using the SamsungVR headset.



Appendix C

Survey utilised for assessing the experience and the quality of the two proposed systems. The survey was administrated for each tested sample and at the end, a comparison between the two was made in order to observe which one is perceived as more suitable for different indoor and outdoor situations.

Session 1

* 1. Gender

- Male
- Female

2. Age

15 — 60

* 3. How well do you think you understand what the idea of the application is?

Not at all — Completely understand

4. Was it something you did not understand about this concept?

* 5. How helpful/useful do you think the concept can be in a situation similar with the one that was described in the test?

Not Useful — Useful — Very useful

6. What is good about the application?

7. Is something not working the way you thought it would?

8. What do you think about the quality of the visualised content?

9. How would you describe the controls of the application?

Very hard	Hard	Moderate	Easy	Very easy

10. How would you describe your experience?

11. What functionality you think is missing from the application?

Images utilised for describing different indoor and outdoor environments that were assessed in the survey: