Virtual Reality for Lighting Simulation in Events

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To my parents, Rita and João

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Abstract

Lighting in events such as concerts, theatres and nightclubs is progressing massively. The technology involved is what enables the highly intense and powerful shows to stand out. In order to ensure great performances, technicians are now using light simulation tools to design, program and preview their shows beforehand. Recent applications consist of elaborate interfaces with complex tools and render engines to provide the most visual feedback in advance, avoiding production costs and stress prior to an event. However, these interfaces tend to be overwhelmingly sophisticated, requiring considerable learning efforts. Also, and despite the advancements on the visualization side, there is a lack of immersive 3D interaction capabilities, which could provide a far more realistic user experience.

This work tackles this challenge. We propose an immersive light design and pre-visualization interface, aiming to increase the preview realism and suit people with no experience in stage design. Our prototype, VRLight, couples a head-mounted display and a gesture-based interface for visualization and real-time interactive light simulation. The design and control tasks are split in order to increase creativity and focus on both sides. In the immersive environment, the director performs the design and pre-visualization routines, and complex control is externally carried out by the technician, using any light console of his preference. To validate this solution, a group of non-expert users was involved in a set of tests. Results shown that users with no knowledge prior to the evaluation could easily perform stage design tasks.

This thesis follows the new **Project Work** structure, started this year in the Computer Engineering course.

Keywords: VRLight, virtual reality, immersive visualization, stage lighting design, events.

Resumo

A tecnologia associada à iluminação em eventos - concertos, teatros e discotecas - progride a grande ritmo. De forma a garantir performances notáveis, os técnicos de luz recorrem a ferramentas de simulação da iluminação para produzir, programar e pré-visualizar os seus espetáculos. As aplicações mais recentes consistem em interfaces elaboradas e complexos mecanismos de renderização que visam possibilitar o maior nível de feedback de antemão, evitar custos de produção e stress antes de um evento. Contudo, estas interfaces têm tendência a ser demasiado sofisticadas, requerendo um alto esforço de aprendizagem. Para além disso, e apesar da evolução no que toca ao aspecto gráfico, faltam explorar técnicas de interacção imersiva em 3D, que oferecem uma experiência bastante mais realista ao utilizador.

Este trabalho foca-se nesse desafio. É proposta uma interface imersiva de desenho e pré-visualização da iluminação, com vista a aumentar o realismo da visualização e passível de utilização por pessoas sem experiência. O protótipo VRLight junta óculos de realidade virtual com uma interface baseada em gestos para a visualização e interacção em tempo real com a simulação. As tarefas de desenho e controlo são separadas para aumentar a criatividade e concentração. No ambiente imersivo, o director realiza rotinas de desenho e pré-visualização e o controlo é realizado externamente pelo técnico de luzes, utilizando qualquer consola da sua preferência. Para validar esta solução, foi envolvido um grupo de utilizadores sem experiência. Os resultados mostraram que utilizadores sem qualquer conhecimento anterior conseguiram facilmente realizar as tarefas de desenho de palcos propostas.

Esta tese segue a nova estrutura de **Trabalho de Projecto**, iniciada este ano no Mestrado de Engenharia Informática e de Computadores

Palavras-chave: VRLight, realidade virtual, visualização imersiva, iluminação de palcos, eventos.

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List of Abbreviations

2D Two-Dimensional

3D Three-Dimensional

AR Augmented Reality

CAD Computer-Aided Design

CMOS Complementary Metal–Oxide–Semiconductor

DoF Degrees of Freedom

DJ Disc-Jockey

DMX Digital Multiplex

FPS Frames Per Second

HMD Head-Mounted Display

IP Internet Protocol

LCD Liquid-Crystal Display

LED Light-Emitting Diode

PC Personal Computer

PDA Personal Digital Assistant

SDK Software Development Kit

UDP User Datagram Protocol

USB Universal Serial Bus

VJ Video-jockey

VR Virtual Reality

WIMP Window Icon Menu Pointer

Chapter 1

Introduction

Stage lighting is the craft of lighting as it applies to the production of theater, dance, opera and other performance arts. Several different types of stage lighting instruments are used in this discipline. In addition to basic lighting, modern stage lighting can also include special effects, such as lasers and fog machines. Concerts, theaters, festivals or nightclubs require hundreds of light fixtures to provide the intense shows we can see nowadays. To achieve great performances and reduce stress prior to an event, like in numerous industries, light simulation is becoming a necessity. Fields such as architecture [1, 2] or the automotive industry [3] now require imperative tests over illumination in their products, where lighting designers mistakes are no longer tolerated.

In stage lighting, the existing software to pre-program and pre-visualize the lighting behavior consists of powerful rendering applications with an abundant set of tools to fulfil the designers needs. However, these tools consist of complicated user interfaces that require massive learning efforts and time consuming tasks. Furthermore, new interface possibilities such as immersive 3D environments and gesture-based interaction have yet to be tested.

This thesis follows the new **Project Work** structure, started this year in the Computer Engineering course.

1.1 Motivation

The number of live events has increased exponentially in recent times, mostly due to the loss of revenues caused by piracy in the music industry, which forced an increase in the number and quality of live performances [4]. Coupled with this growth, the technology involved in such events is undergoing major changes. The need to throw bigger and more complex events is rising fast and the production stage is a massive challenge.

Complex lighting systems require considerable light and controller pre-programming, making the pre-visualization stage play a crucial role in successful events. The main issue comes with the sophisticated interfaces, that require excessive efforts on learning and further light programming. The creative stage is therefore affected by these obstacles.

Several applications are already fulfilling the demand for previewing and controlling capabilities using a 2D screen with 3D visualization, and providing a huge set of design and light control tools to comply with the different sceneries and lights involved. However, the possibility of a lighting technician to tailor, automate and preview the light show beforehand in an immersive 3D environment has yet to be explored.

The interest to preview stage lighting beyond regular monitors was confirmed in a meeting with theater lighting experts, in the beginning of this thesis. This chance to discuss the future of stage lighting design with the people responsible for countless theater lighting performances in Portugal, opened up a unique opportunity to explore new options in lighting design pre-visualization.

1.2 Problem description

There are three main concerns in event lighting production: stage design, light pre-visualization and control. Stage lighting specialists now make use of powerful, but complicated software, to pre-program lighting control consoles and preview their performances. In spite of realistic results, these applications still lack of more intuitive interfaces, 3D realistic feedback and real-time capabilities.

The existing software helps designers to achieve their goals, but in a very complex and time-consuming way. All the steps involved require a lot of interface knowledge and the wishful level of abstraction between light programming and the creative design of the show is somewhat demoralizing. On the other hand, with the light programming stage complete, pre-visualization tools are now an excellent help, but still in flat 3D images in 2D screens.

1.3 Proposed approach

This project proposes an **immersive virtual reality solution for stage lighting simulation**, using new visualization instruments, which deliver an insider point of view of the simulation. Together with gesture-based interaction, this approach is proposed to deliver a more intuitive and realistic preview, reducing the learning effort with a simpler interface, in an environment with free movement capabilities for the best preview of the light show.

From the discussion with the lighting experts group, head-mounted displays were chosen as the visualization platform for our solution. With these devices, the preview can be done using only the headset, which even provides camera rotation via head movement. This immersive feeling delivers an intense pre-visualization scenery, still missing in commercial stage design tools nowadays, and not yet studied in this field, to the extent of our knowledge.

In order to validate our approach, a user test evaluation was conducted. The prototype was set to be tested with lighting experts, and against existing software. However, after initial talks with the lighting experts group, the team's schedule did not allow to fit on the project's deadlines. The tests were made with non-expert users and the comparison with commercial software was not possible due to the high interface complexity, which could not be used without several hours of learning before the test. Our solution was validated by confirming the assumption that **all tasks are executed with success, even by non-expert lighting users**. Future work will ensure the validation against existing software.

1.4 Document outline

The remainder of this document is divided into four parts. The next Chapter provides an overview of the state-of-art in lighting simulation applications, light control, user interfaces for lighting and music and immersive visualization and interaction technology. In Chapter three we describe the proposed architecture in detail. We follow it with a user validation, presented in the fourth chapter, using data collected from test sessions. Finally, in Chapter five we present an overall discussion of our work, delineating conclusions and introducing perspectives for future work.

Chapter 2

State of the Art

Lighting simulation was developed to fulfil the need to preview the effect of light in certain environments. Having an idea of what the resulting illumination will become in certain industries, such as architecture or product design, made professionals more aware and prevented lighting issues involved in the design process [5]. These are very good news regarding the avoidance of expenses involved in lighting design mistakes.

In event production, the use of intelligent lighting - e.g. moving lights with different colors and intensities - makes the preview far more demanding in terms of computation requirements and user interface complexity, since dynamic lighting requires a whole set of controls and programming behind. Interfaces usually become overwhelmingly complicated to use, and pre-visualization is harder to achieve without several hours of learning or can only be done with large teams. On the other hand, the preview software available still relies on regular monitors for event pre-visualization, although the powerful rendering capabilities and endless light fixtures and other stage assets.

This Chapter first covers the main lighting control hardware and software, as well as lighting simulation applications for both static and dynamic lights. Next, are presented the recent developments in user interfaces for lighting and music, along with new immersive visualization and interaction devices that may be used instead of the regular keyboard and mouse.

2.1 Lighting simulation applications

Lighting simulation is an inevitable preview phase in countless industries. Giving designers the ability to sneak peek their final work can reduce production costs and future misconceptions, by providing the most accurate view of the resulting product or testing. These kind of applications have now been adopted not only in events, but also in interior design [6], automotive industries [7], biology [8] and every light-influenced business.

When developing an application for lighting simulation, the main concern is to make the user get the most accurate and realistic preview possible. Shikder [9] studied the performance and realism of four lighting simulation tools for ambient light in static environments. Focusing on the accuracy in calculating illumination level and luminaire number for a target space, his work revealed very close results between the four main softwares being used nowadays - DIALux[1] (Figure 2.1), Relux[2] (Figure 2.2), AGI32[3] and Ecotect[4] + Radiance[5]. These are competing applications developed for professional light planning used by thousands of light planners and designers worldwide. Providing tools from scene modeling to daylight and artificial light adjustment, these applications are a good example of how good and photorealistic light simulation can get, and how architects or product designers can improve their work skills. By applying the right textures to the objects in the scene, the final light will end up being very close to the one predicted in the simulated model.

Due to their main targets, these applications only cover static lights and provide static pre-rendered graphics exclusively. The ability to change the viewing angle requires a full render for the new view, which makes navigation in the model impossible.

Boyles et al. [10] were, however, able to build an interactive virtual reality (VR) environment to test lighting in static environments such as a living room, illustrated in Figure 2.3. Boyles was able to create a 3D environment in a "*CAVE-like*" display with head tracking and four stereoscopic, rear-projection screens. Navigation through the room and light intensity control were possible with very good realism levels. However, to achieve performance by maintaining the high frame rate necessary for VR displays, pre-rendering was necessary to make a reliable solution - render times for light maps and ambient occlusion maps[6] varied up to 48 hours on a render farm of up to nine PC computers.

Figure 2.1: DIALux simulation.

Figure 2.2: Relux simulation.

[1]DIALux - `http://www.dial.de/DIAL/en/dialux.html`
[2]Relux - `http://www.relux.biz`
[3]AGI32 - `http://www.agi32.com/`
[4]Ecotect - `http://usa.autodesk.com/ecotect-analysis/`
[5]Radiance - `http://www.radiance-online.org/`
[6]Ambient occlusion models the appearance of objects under indirect illumination [11].

Figure 2.3: Boyles VR environment.

Event lighting brings a much bigger challenge to light technicians. With the addition of dynamic lights and lots of different fixtures, such an application, developed for static light environments, is not enough. In Section 2.3, we cover the major goals and tools for dynamic lighting today.

2.2 Light control

Light control developments are growing fast. Nowadays, illumination control is provided in many different ways - regular light switches, dimmers, sensors, timers and so forth. Studies into new ways of light interaction [12, 13] and automation are increasingly frequent in several of industries - e.g. hotels [14]. With the appearance of new types of lighting and controllers, researchers are now investigating new possibilities in light interaction. Magielse and Offermans [15] are studying new ways of giving freedom of control to the user in a comprehensive manner, using tangible and multi-touch interfaces. *LightPad* and *LightCube* are two of those interfaces introducing expressive inputs, such as touch, duration and force over a pad, or the ability to choose between different presets (faces of a tangible cube), related to different activities.

These kind of studies corroborate that lighting control is adapting to changes, and event lighting is, by far, the most complex control task in the light business. To control lights in events, technicians make use of light consoles. A common lighting console [16] (Figure 2.4) also called a light board, lighting board, or lighting desk is an electronic device used in event lighting to control multiple lights at once. Consoles range from entry-level models, that operate a dozen or more fixtures, to the very upper range models, that can operate hundreds or thousands of fixtures. All lighting control consoles can command dimmers which change the intensity of the lights. Modern consoles can also control intelligent lighting

Figure 2.4: Lighting control console.

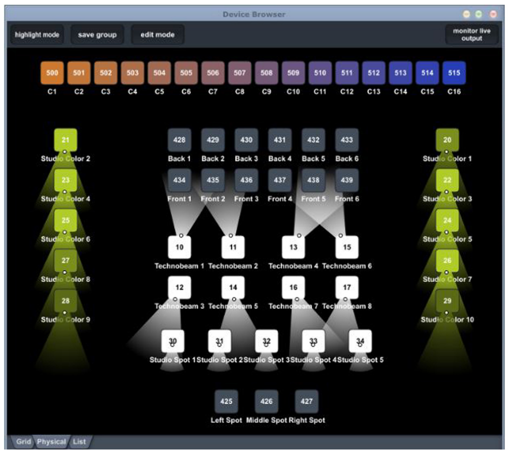

Figure 2.5: D-PRO controller software.

(lights that can move, change colors and gobo patterns[7]), fog machines and hazers, and other special effects devices. Lighting consoles communicate with the dimmers and other devices in the lighting system via DMX-512, an electronic control protocol.

DMX-512[8] is a standard that describes a method of digital data transmission between controllers and lighting equipment and accessories. It covers electrical characteristics, data format, data protocol, and connector type. This standard is intended to provide for interoperability at both communication and mechanical levels with controllers made by different manufacturers. DMX-512 is detailed in Section 3.4.

Lighting control consoles or desks have seen great development. Software arrived to this industry and is changing the way shows are being prepared and executed. Complex lighting now seen in big events like concerts, theatres, festivals and nightclubs is extremely hard to control live, due to the number of light fixtures and their unlimited options like movements, colors, dimming, and so forth. Many complex tasks are carried out on lighting consoles - e.g. recording cues[9], fading between states, color mixing and moving light control - and they are often complex PC based devices needing experience and skill to operate.

Nowadays, a technician can make use of a lighting controller in hardware, software or both combined. However, complex shows pre-programming always require software aids for previewing and automating tasks that are triggered during the exhibition. D-PRO (Figure 2.5) is a software-based lighting controller with plenty of advanced features for the most demanding lighting professionals. Nevertheless, this control software does not provide pre-visualization options, which can be achieved with the applications presented in the next section.

[7]Gobo [16, p. 254] - pattern inserted in the focal plane of a luminaire to project an image.
[8]DMX-512 - `http://www.usitt.org/content.asp?contentid=373#WhatisDMX512`
[9]A Cue is an automated scene with timing attributes to control e.g. the fade in and out times.

2.3 Virtual lighting applications for event simulation

Previewing the effect of lighting on a particular event, with real-time capabilities, is now possible with specialized software. Light designers now have the tools to pre-program a show before arriving at the venue - a process that can reduce production costs, on-site time and stress, while nurturing creativity.

There are numerous commercial solutions to virtualize lighting in events. This software joins stage design tools, lighting control programming and the ability to preview the results with real-time capabilities. A complete package may allow for 2D and 3D stage design, as well as of all types of rigging and light fixtures, controller programming and, most important, preview the results by rendering the virtual show.

Stage model design and preview can be achieved using computer-aided design (CAD) software, which also provides rendering, mesh modeling and visualization features. CAD tools are very important for today's architects, builders, designers and especially buyers to navigate and visualize through several perspectives how the final building/product/venue will look like [17]. However, for dynamic light visualization with real-time control capabilities, a regular CAD software is not enough.

Specialized CAD lighting design tools, such as WYSIWYG[10], have already rendering capabilities for real-time pre-visualization, which provide powerful light show virtualizations. However, some designers still prefer to have the stage design made with a standard CAD tool, such as AutoCAD or 3D Studio Max and then import their drawings into a dedicated visualization software.

With a lighting simulation tool, there are two main stages to preview the final result - **stage design** and **visualization**. Cadena [16, p. 379] suggests that the designer should go through the basic steps showed in Figures 2.6 and 2.7 for stage design and visualization, respectively.

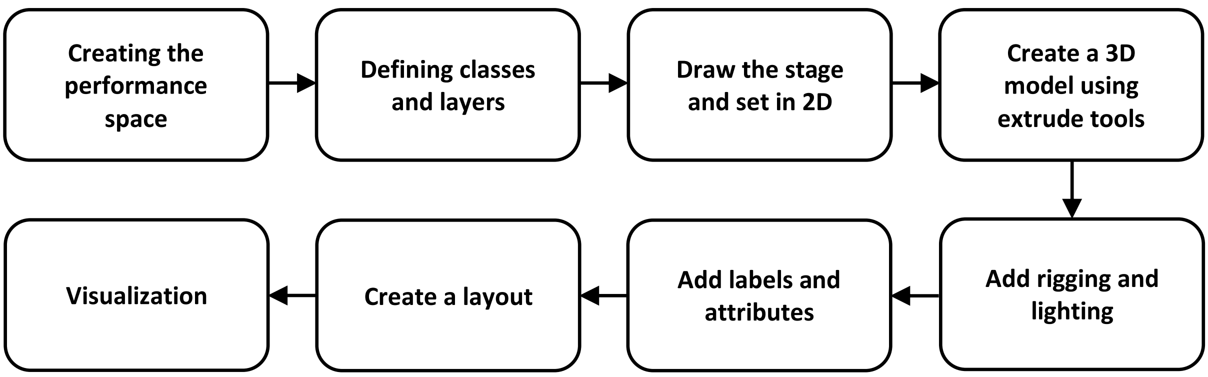

Figure 2.6: Stage design diagram.

[10] WYSIWYG - `http://cast-soft.com/wysiwyg/overview`

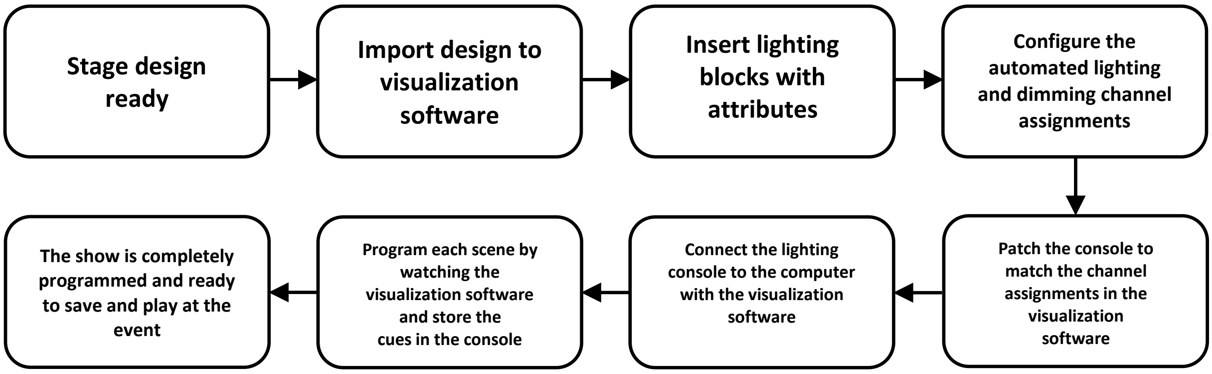

Figure 2.7: Visualization diagram.

All the steps required to successfully design a stage for a light performance pre-visualization are detailed in the appendix A - **From design to pre-visualization**.

When analysing the main existing tools for pre-visualization, there are three that stand out from the rest - **ESP Vision**[11], **WYSIWYG** and **grandMA 3D**[12]. Other competing applications such as Capture[13] and Martin ShowDesigner[14] also play an important role in the pre-visualization stage, with similar levels of realism and performance, but with a smaller number of users.

ESP Vision (Figures 2.8 and 2.9) is considered one of the standards in pre-visualization applications for lighting. Designed for the world of concert lighting, Vision connects to almost any offline editor and many real life consoles, allowing a designer to cut down on time. Vision also offers pyrotechnical effects and is able to produce entire videos of programmed cues, live. Nevertheless, Vision does not allow to draw stages from scratch.

Figure 2.8: ESP Vision simulation.

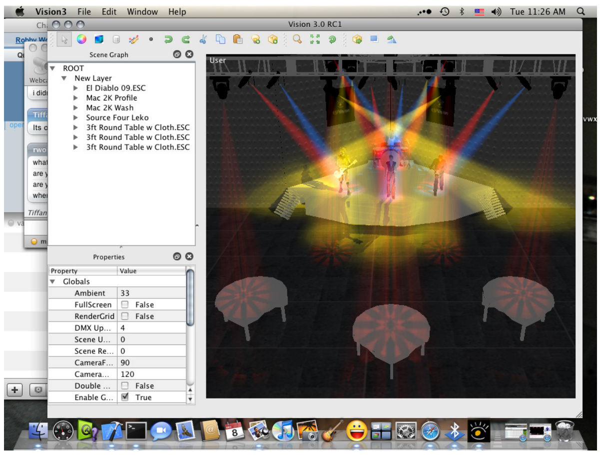

Figure 2.9: ESP Vision user interface.

[11]ESP Vision - http://espvision.com/
[12]grandMA 3D - http://www.malighting.com/
[13]Capture - http://www.capturesweden.com/
[14]Martin ShowDesigner - http://www.martin.com/

Figure 2.10: WYSIWYG preview and live results.

On the other hand, WYSIWYG software (Figure 2.10) includes a fully fledged plotter program, as well an extensive in-program library. Features such as enhanced beam renderings, correct footprints and shadows, hotspots, and other enhancements make it an extremely powerful visualizer. These two applications do not feature any integrated controller for pre-visualization. They can, however, be connected to many real life consoles, as well as many offline consoles, which send the desired controls to the lights in the simulation in real-time. Without an external controller, it is still possible to pre-program the lighting controls and watch the entire show in advance.

Another big competitor in the pre-visualization field is grandMA 3D (Figures 2.11 and 2.12). This design and pre-visualization tool is produced by MA Lighting - international leader for computer-controlled consoles and the preferred manufacturer in the lighting console business for big concerts, with the massive grandMA2, illustrated in Figure 2.13. GrandMA 3D, similar to ESP Vision, will render live a full lighting rig in real-time. Like WYSISYG, 2D drawing facilities and a library of basic graphical elements are provided,

Figure 2.11: grandMA 3D simulation.

Figure 2.12: grandMA 3D simulation.

and pre-made designs can also be imported from another CAD modelling tool.

Maximum speed and good rendering quality are the two major expectations in pre-visualization software - as seen before in previous figures, the quality is at a good level when comparing with the final results (Figure 2.10). In addition, some tools even feature stage design capabilities, while others accept drawings made with specific tools. These applications solve almost any challenge in light production nowadays with powerful realism settings. However, the skills required to work with these interfaces, along with the time needed to achieve good results, make the simulation stage an intimidating and sometimes optional process.

2.4 User interfaces for lighting and music in events

User interfaces for lighting control started with hardware only, with the consoles introduced in Section 2.2. Recently, new software tools came to support, or even end the lighting desks tasks, by providing new interfaces and far more powerful ways to interact with lights. GrandMA onPC (Figure 2.14) is a compelling tool to pre-program the lighting console's behaviour or to fully control the whole light rig by itself. This way, technicians can use grandMA2 console (Figure 2.13) together with the onPC software, or indeed use the software alone, depending on their preference.

Despite being quite a useful tool, grandMA onPC still features a very difficult interface that, in the pre-visualization stage, can definitely impair creativity, since it is still needed to use together with grandMA 3D for the simulation control.

The multi-touch approach

Although already being used in some performance fields, such as music production [18] and VJing [19], the multi-touch approach in lighting simulation is just getting started. SmithsonMartin[15] is the first com-

Figure 2.13: grandMA 2 console.

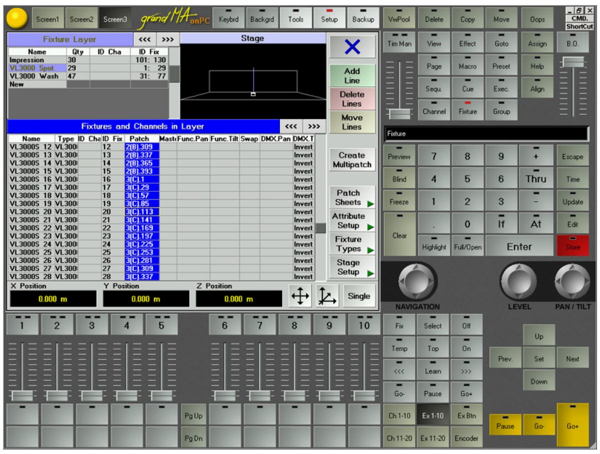

Figure 2.14: grandMA onPC software.

[15] SmithsonMartin - http://www.smithsonmartin.com/

pany developing multi-touch surface solutions for music and lighting to be used with existing software. Their solution - the Emulator - is the only touch-screen program that can merge the software to be controlled with the touch interface making a software feel like it was natively designed for use with multi-touch (Figure 2.15). GrandMA and WYSIWYG are also included in the options, among many others. Figure 2.16 shows how the grandMA2 console is virtualized using the Emulator.

This is a big step for lighting control and simulation interfaces, since it simplifies a lot the whole process. Although some studies reveal higher levels of performance with tangible controls [20, 21] - e.g. faders, knobs, buttons - the Emulator provides a fully configurable interface which can be adapted to every user's needs and thus, greatly simplifying the process as well as giving much more durability to the hardware. The use of multi-touch devices with much cleaner and editable interfaces is a big step being taken nowadays. Not only in the light business, but also in music production and live performance, the use of multi-touch instead of analog equipment is starting to be accepted by artists.

Lopes et al. [22] made a Virtual DJ solution to bridge the gap between traditional and virtual setups, through the development of a multi-touch interactive DJing application - Mt-Djing[16] - illustrated in Figure 2.17. This approach revealed very good results as being a suitable option for digital DJs to avoid the traditional input devices such as a mouse, a keyboard or dedicated hardware controllers. The feedback obtained by the DJs involved in the project raised multi-touch to a strong alternative in the music performance field. Later, Traktor, the most renowned DJ software, also developed solutions[17] for smarphones and tablets - still only available for iPhone and iPad devices. SmithsonMartin also solved the need in the Emulator (Figure 2.18).

In the VJing[18] field, Taylor et al. [23] developed VPlay, a multi-touch tabletop application that allows users to mix and manipulate multiple video streams in real-time. Here we have another example of a

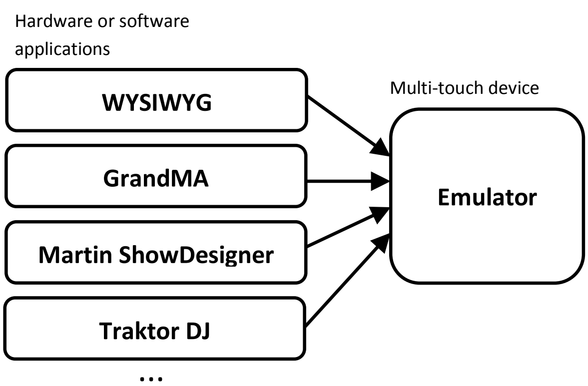

Figure 2.15: Emulator solution.

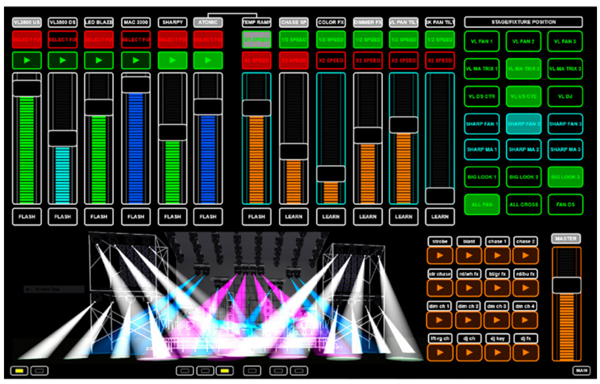

Figure 2.16: grandMA2 in Emulator.

[16]Mt-Djing - http://vimeo.com/24818342
[17]Traktor DJ - http://www.native-instruments.com/en/products/traktor/
[18]VJing [23] is a form of live video performance art, often undertaken with DJs and musicians to create a visual backdrop within nightclubs and other music events

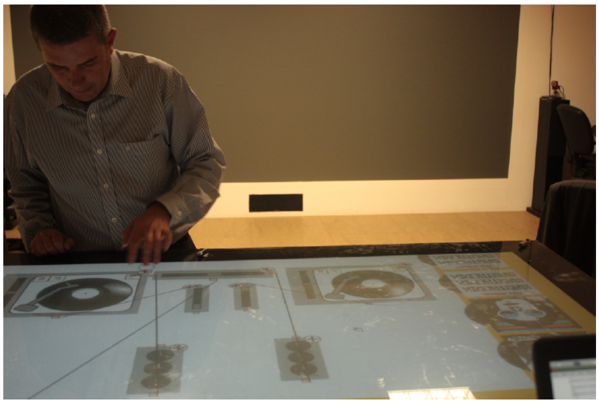

Figure 2.17: Mt-Djing.

Figure 2.18: Traktor DJ in Emulator.

performance kind of task going into the multi-touch field. Since VJing works with video, the results though showed some difficulties when VJs were focusing their visual attention on the projected displays, yet still interacting with the system. This problem of split attention occasionally led to situations where the VJ lost acquisition of a digital interface control, momentarily disrupting a mix. In critical live situations, this can also represent an issue when controlling lights. In pre-visualization the pressure is reduced since lighting control goes a lot through pre-programming cues, that avoid much live interaction with the controller. However, a multi-touch controller in stage lighting should need to have a preview window for users to keep track of lights and hands at the same time. A small visualization window in the tablet would help having a full-time feedback of the lights, independent of what screen users would focus their attention on.

All these new multi-touch approaches ensure that the tradional hardware controllers for performing arts like lighting and music can be replaced by simpler and most durable multi-touch interfaces, with the precious possibility of having multiple software interfaces for the same purpose in the same piece of hardware.

Due to the similarity of the interaction with light control, when compared to DJ controllers, it is possible to certify beforehand the multi-touch potential in lighting pre-visualization. In general, complex interfaces with lots of faders, knobs and buttons, when virtualized, tend to become far more complicated if using only the standard input devices - keyboard or mouse. Studies [24] reveal a considerable time reduction in task completion when switching from a regular mouse to a multi-touch tablet, when performing basic interface actions.

Recent developments on lighting user interfaces

Regarding the new interface possibilities that could apply to event lighting, Bartindale et al. [25] developed ThorDMX[19], a lightweight prototyping toolkit for rapid and easy design of new stage lighting controllers. This toolkit provides a simple framework for prototyping new lighting interfaces in both hardware and software. With the objective of simplifying the control process and stage design, users can

[19]ThorDMX - `http://youtu.be/b3_wSXPZ7rY`

now develop their own tools for lighting control in an easy way, instead of diving in complex software tools.

ThorDMX was created to simplify designers' and controllers' tasks but also with the ability to involve the crowd in the light show by enabling to control a limited number of colored lighting around the venue. This can be done using a server side application to receive commands from any device, which then sends the information to the light fixtures. Figure 2.19 shows a simple mobile interface consisting in a fader based controller for a lighting rig, made with this toolkit. Providing a server to receive multiple commands from different people with their own lighting controllers for the same stage lights is a powerful way of dividing the work flow, foster creativity and even make the crowd feel like they are part of the show with their own limited controls over the system.

ThorDMX features a venue editor as well (Figure 2.20) which also brings new ways of stage design that can be split through many designers, in a much lighter interface and, by far, easier way of use.

Light control over a network is a huge improvement which may play a key role in event lighting in the future. This approach was also studied and developed by Jiang et al. [26], who analysed a server solution, capable to control lights over wired, wireless, GPRS and SMS networks. With all those options, portable computers, handheld computers (PDA) and mobile phones can now be part of the controller system, allowing for numerous interface possibilities.

Multi-touch and mobile interfaces are slowly taking over the control of light, music and video performances. Mostly due to the configurable interface capabilities delivered by these new tools, artists and designers can now build their own controllers to face any challenge. By having a simpler and targeted user interface, and far more durable and portable hardware, multi-touch surfaces seem like a good option for light control. However, with extremely complex consoles in professional stage lighting today,

Figure 2.19: ThorDMX mobile light console prototype.

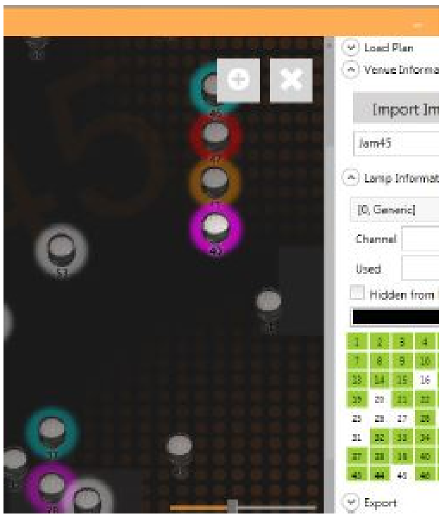

Figure 2.20: ThorDMX venue editor interface.

technicians with full knowledge and work habits on their equipment may feel the need to use that same gear in pre-visualization. Making use of their tools in the preview stage is an unbeatable advantage as soon as their console may be pre-programmed without having a full lighting rig setup for that purpose.

All these improvements in user interfaces for stage design and light control open up several new possibilities. However, the visualization side still relies on regular screens for pre-visualization. Making use of simpler interfaces with immersive virtual reality solutions can introduce new degrees of freedom to the user. Next Section covers the main immersive visualization and interaction devices being used nowadays, which can represent good improvements in the overall user experience in event pre-visualization.

2.5 Immersive visualization and interaction

Visualization in virtual reality environments can be broadly divided into two types: non-immersive and immersive. The immersive is based on the use of head-mounted displays or projection rooms (e.g. HMD's [27], CAVEs [28, 29]) while the non-immersive virtual reality based on the use of monitors. The notion of immersion, is based on the idea of the user being inside the environment.

Interacting on an immersive environment drops the interest in known devices such as a keyboard or mouse. Immersion in virtual reality relies on new instruments to provide a more intuitive way of interacting using gesture-based or hands-free interaction for example.

In the stage lighting industry, immersive pre-visualization and interaction has yet to be explored. This Section covers the main devices and solutions for visualizing and interacting on immersive environments.

2.5.1 Head-mounted displays

A head-mounted display or helmet mounted display, both abbreviated HMD, is a display device, worn on the head or as part of a helmet. HMD's have two LCD screens to display a different image to each eye and draw the virtual world depending on the orientation of the user's head via a tracking system. Figure 2.21 illustrates an example of a HMD. HMD's can display the same picture in both eyes or be stereoscopic by combining separate images from two offset sources. Both of the offset images are then combined in the brain to give the perception of 3D depth.

VR may also be mixed with reality to create an augmented reality (AR) environment. In augmented environments, the vision of the real environment is overlaid with information from the virtual environment. AR displays can be rendered on devices resembling eyeglasses - optical head-mounted displays (Figure 2.22). Versions include eye wear that employ cameras to intercept the real world view and re-display its augmented view through the eye pieces and devices in which the AR imagery is projected through or reflected off the surfaces of the eye wear lens pieces.

Figure 2.21: VR Head-mounted display

Figure 2.22: AR Optical head-mounted display

Using this type head-mounted displays, users can increase the level of immersion in the environment, feeling part of it, which improves the feedback of a simulation to a far more intense level of realism. The interaction here needs other approaches than the regular keyboard or mouse. New ways of interacting are emerging to comply with this new immersion capabilities.

2.5.2 Gesture-based interaction

Gesture-based interaction devices are controllers that act as an extension of the body so that when gestures are performed, some of their motion can be conveniently captured by software. Mouse gestures are the most well-known example. However, other devices are emerging with different approaches and technologies, which support immersive visualization by delivering more degrees of freedom (DoF). Also called post-WIMP devices, which go beyond the Windows Icons Menus and Pointing, they allow straightforward direct mapping between device movements and rotations and corresponding effects on the three-dimensional space. Some of the new options are presented next.

The Nintendo **Wiimote**[20], illustrated in Figure 2.23, is equipped with an infrared camera and a three-axis accelerometer and gyroscope, which gives six DoF. Cochard and Pham [30], showed how the accelerometers and optical sensor of the Wiimote can enhance the user experience within a 3D environment by allowing the user to move 3D objects directly with the movements and gestures of their hands. Lee [31] used a Wiimote and took advantage of its high resolution infrared camera to implement a multipoint interactive whiteboard, with finger and head tracking for desktop virtual reality displays.

Similar to the Wiimote, the Sony **PS Move**[21] (Figure 2.24) also has a three-axis accelerometer and gyroscope. However, thanks to the use of a magnetometer it provides a better precision and greater control of movement. Also, unlike the Wiimote's built-in camera, that transmits its targeting position according to the location of the infrared sensor bar, the PS Move uses the PlayStation Eye camera to track its position thanks to a luminous sphere on its top. It calculate the distance from the remote to the camera, enabling the tracking of the depth position of controller.

[20]Nintendo - Wiimote - `http://www.nintendo.com/wii/console/controllers`, October 2006.
[21]Sony Computer Entertainment - Playstation Move - `http://us.playstation.com/ps3/playstation-move/product-information/`, September 2010.

Figure 2.23: Nintendo Wiimote.

Figure 2.24: Sony PS Move.

Finally a small device which provides a very accurate targeting precision and greater control of movement is the **SpacePoint Fusion**[22] developed by *PNI Sensor Corporation*. With the use of a magnetometer, a gyroscope and an accelerometer, all three axis self-calibrate and maintain pinpoint accuracy, allowing a better immersion experience. Tests of SpacePoint against the Wiimote's first release showed much higher stability on the SpacePoint. Nintendo's full capabilities come in the new Motion Plus version of the remote, which was not available for testing and development.

2.5.3 Hands-free interaction

With depth sensors, infrared cameras, microphones or any other hands-free devices, interaction reaches another level, in a way that user's are not dependent of an hardware extension of their body to navigate or interact in the environment. Two of the main options nowadays are presented next.

The Microsoft **Kinect**[23], displayed in Figure 2.25, is a device capable of 3D motion capture and voice recognition. To this end, it comes equipped with an RGB camera, depth sensor and multi-microphone array. The camera helps in facial recognition and color detection. The depth sensor consists of an infrared spotlight and a monochrome CMOS sensor, which combined can offer a 3D view of the room, under any lighting conditions. The microphone consists of a series of four microphones that can isolate the voices of the players from ambient noise.

Specialized in hand and finger motions as input, **Leap Motion**[24] (Figure 2.26) is an hardware sensor

Figure 2.25: Microsoft Kinect.

Figure 2.26: Leap Motion.

[22] PNI Sensor Corporation - SpacePoint Fusion - `http://www.pnicorp.com/products/spacepoint-gaming`, 2010.
[23] Microsoft Kinect - `http://www.xbox.com/en-US/kinect`, November 2010.
[24] Leap Motion - `https://www.leapmotion.com/`

device that requires no hand contact or touching, by tracking the user's hand using two monochromatic infrared cameras and three infrared LEDs. This device observes a roughly hemispherical area, to a distance of about one meter and tracks all the hand and finger movement by comparing the 2D frames generated by the two cameras. Leap motion's capabilities were already tested in stage design by Apostolellis et al. [32] in an attempt to prove that it would outperform the mouse for the integral tasks of position and rotation of light fixtures. However, he did not support the hypothesis with the mouse performing significantly better, both in terms of completion time and angular and position errors.

2.6 Discussion

We have now covered many different types of applications and studies about lighting visualization, user interfaces and immersive visualization and interaction solutions. The existing lighting simulation tools offer an excellent platform to preview the effects of illumination, pre-rendered or in real-time. By having a very good perspective of how the event will unfold, event promoters are now starting to use these tools to prepare their shows.

Despite their potential, the complexity thereof is still demoralizing. To achieve some complexity in the simulation, all these user interfaces can become quite confusing, complicating the planning process. This work can only be done in time when divided by large teams. Furthermore, to the extent of our knowledge, the idea of having a 3D immersive or semi-immersive environment to preview the show is an approach that has never been tested in event simulation. As for interaction, all pre-visualization software available still relies on the WIMP concept and, although the efforts to include new tools in the stage design process, there are still a lot of options to be tested.

Table 2.1 presents the main features of the different softwares covered in this section and crosses the more desirable features. It is easy to confirm that all the three competitors suit the needs of stage design and real-time pre-visualization. Real-time rendering is possible in every software, whilst none of the solutions include an integrated light controller. This means that the interaction is only possible with external controllers or pre-programmed cues recorded in the software. GrandMA 3D can be used with the grandMA onPC (Section 2.4) tool for controlling which, although being a software controller, it remains as an external controller needing a lot of pre-mapping between the light fixtures and the controller, prior to the visualization.

Feature / Application	**ESP Vision**	**WYSIWYG**	**grandMA 3D**
Stage design	-†	X	X
Real-time rendering	X	X	X
Integated light controller	-	-	-
3D immersive environment	-	-	-

†only allows importing designs made with CAD modelling tools

Table 2.1: Pre-visualization software feature comparison.

In what the creative stage is concerned, designers may want to test the lighting only, without being much worried about DMX-512 communication mappings and cues between the controller and light fixtures. The level of programming abstraction in this applications is still too low to provide a richer pre-visualization experience. However, the design stage could be split from the control task in order to keep pre-visualization interesting for technicians also. Allowing DMX consoles in the preview stage is already possible in the major softwares studied. Yet, if the design task would be less impaired by the technical issues, the workflow could be improved on both sides.

Concerning controller interfaces, ThorDMX showed evidences of being a powerful toolkit for controller prototyping. Developed to be used with real lighting systems, it provides a good level of abstraction in light mapping to the controller and makes mobile control a viable option for technicians to shift from analog light desks to multi-touch tablets with the required controls to the venue only. This interface creation and simplification could also be used for pre-visualization. Since only real lighting systems are covered, using ThorDMX to build a mobile device controller for a virtual rig would facilitate the interface interaction, when comparing with the existing sophisticated applications - e.g. ESP Vision, WYSIWYG, grandMA 3D, etc. However, whether talking about small or big venues, hardware or software controllers, in any platform, all need to work with the pre-visualization software. And even looking at small prototypes like ThorDMX, that still rely on DMX to ensure their convenience for stage lighting, the main communication protocol must be accepted in any future prototype.

When it comes to immersive virtual reality for lighting simulation, a solution is still yet to come. Head-mounted displays, besides their visualization capabilities, can provide a greater sense of immersion when simulating a light show. In a collective work between designer and technician, the designer could make use of a headset to pre-visualize the show with an immersive perspective, supported by a technician delivering light control and previewing the results through a second visualization device, such as a monitor.

Our team had the chance to contact a lighting experts group and discuss a few visualization options for the future of stage lighting pre-visualization. Having tested available software to this end, our guests showed big interest in testing a pre-visualization software supported by a HMD. With this motivation, and not finding any solution to this request, the need for an immersive virtual reality system to preview lighting in events was clear.

Chapter 3

VRLight

VRLight is a prototype software delivering an immersive light design environment which combines virtual reality for visualization with gesture-based interaction devices for light design. All light control tasks are carried out by a second user, the light technician, who supports the director by providing real-time light control to the scene. This virtual reality solution for lighting simulation in events combines all these new technologies, with the two main highlights being simplicity and interaction. Regarding the necessary learning effort to achieve results with the available tools, VRLight can make the task much easier and, therefore, leaves more space for creativity. This prototype was developed from the investigation on existing lighting pre-visualization tools, immersive visualization devices and gesture-based interaction approaches.

Our prototype was developed for stage lighting design purposes. The challenge of building a tool to quickly preview a light show with little learning effort was the main goal. This Chapter elaborates VRLight solution starting with a conceptual point of view, architecture description and all features enabled by this new software.

3.1 Conceptual description

This prototype provides an immersive light design environment which allows the user to feel inside the real scenery. Changing a light projector from a 10 meter height structure is now as easy as pointing to the fixture and selecting a different one. This virtual reality feeling is where VRLight stands out. The show director can easily set the whole lighting rig by himself and preview the results in real-time. On an immersive environment, the pre-visualization method becomes far more realistic, with the ability to look anywhere in the scene and obtain an insider sensation of the design process and the resulting light show.

VRLight separates the artistic task from light control, allowing the director to focus only on light fixture choosing, placement and aiming in the immersive environment. The entire light control backup is provided by a light technician, working with any light controller device of his or her preference. Figure 3.1

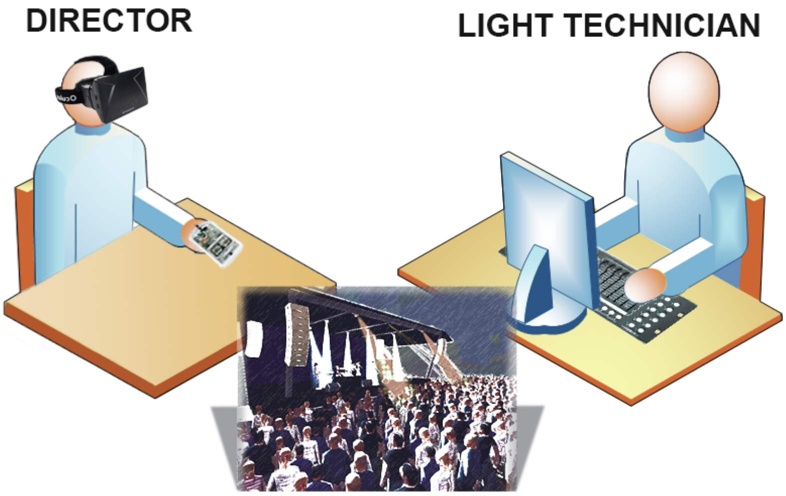

Figure 3.1: Conceptual overview.

shows an concept overview of the work process. Using a head-mounted display, the director gets an immersive view of the virtual environment where all the action is taking place. With a pre-modeled scene ready - e.g. theater, club, etc - the user handles a gesture-based interaction device to allow movement and light editing. By communicating with the light technician, who follows the process on a separate screen, the director can demand any light parameter change to obtain real-time feedback of the setup behavior and make fixture changes or aim lights in different directions, all in real-time and with free movement in the scenery. This unique approach lets the user feel the light show from any location, from either the crowd's perspective, the musicians' or any other desired view angle.

3.2 Architecture description

VRLight was developed in Unity3D game engine thanks to its powerful 3D environment for modeling and the script-based logic for all operations, which allowed a great level of abstraction and powerful real-time rendering. The application runs on a single computer and connects to an input module for interaction and light control and an output module for visualization in two different devices. Figure 3.2 illustrates the architecture diagram. All light fixture resources are stored in a data folder containing the light modules and their behaviors. Also, a *config* file is used for both loading and saving the lighting rig for further work. This file keeps the fixture list, DMX channels and light orientation in the environment.

The **input module** is divided in two different components - **interaction** and **light control** - carried out by a light designer (director) and a light technician respectively. To interact in the environment - light editing menus and user movement - the designer uses ***SpacePoint Fusion***. This gesture-based interaction device was chosen thanks to its very stable gyroscope component which allows one to add a cursor in the 3D environment using the pitch (X-axis), yaw (Y-axis) and roll (Z-axis) values. The Nintendo Wiimote can also be used but with a sensitivity downside explained in Section 3.3. As far as light control

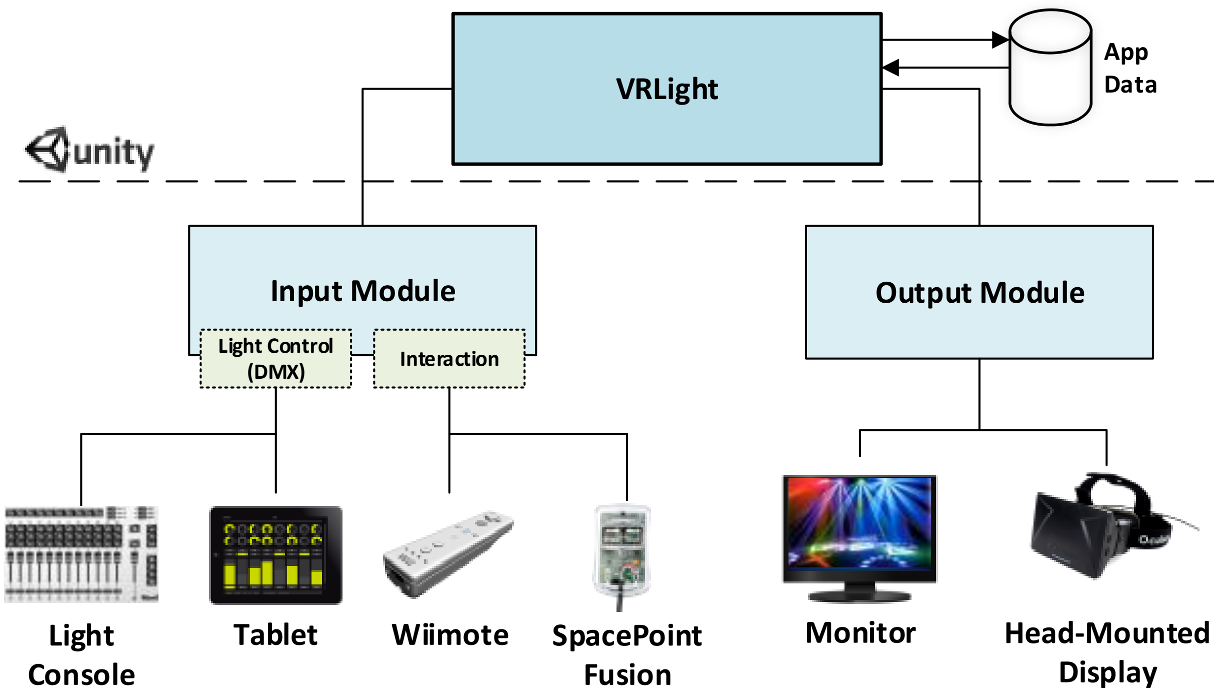

Figure 3.2: Architecture overview.

is concerned, VRLight is ready to connect to any controller having the DMX-512 (DMX) communication protocol. From simple DMX software running in the same machine to complex light consoles with a DMX-to-USB device or wireless connection to the computer, the application is ready to read any desired input. DMX and the detailed connection to external controllers is explained in Section 3.4.

The **output module** provides visualization platforms to the designer and the technician. It is composed by the **Oculus Rift** head-mounted display for immersive visualization and an external monitor for the light technician to acquire feedback from the simulation. The headset provides an insider view of the scene, with the immersive feeling allowing head movement in any direction or axis. The monitor displays a variety of views to the scene, allowing the technician to follow the preview from the most suitable angle.

3.3 Immersive visualization and interaction

VRLight provides a unique experience when it comes to lighting pre-visualization. Immersing in a modeled scenery and previewing the light with a virtual reality headset lets light designers step inside their venue, test the lights and ensure a perfect performance as if they had been there before.

Visualization is achieved with the Oculus Rift headset (Figures 3.3 and 3.4) connected to the core using the Unity3D plug-in from the Oculus SDK. Due to the danger of hitting something while using this device, it is impossible to wear it and walk around the room, since an HMD doesn't allow to see other than the virtual environment. For this reason, the director interacts while sitting next to the light technician. Al-

Figure 3.3: Oculus Rift.

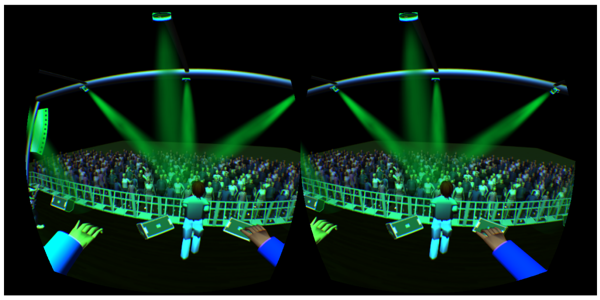

Figure 3.4: Oculus Rift output.

though this imposes limitations in what concerns movement inside the scene, the user has two different options when using the SpacePoint gyroscope, explained in Section 3.8.

The powerful immersion capabilities of this headset are very good when compared to older models such as the Z800 3D Vision[1] from eMagin Corporation. However, the Oculus Rift still has a lot of room for improvement in order to provide true high-definition on the same level as the one we obtain from regular screens. Nevertheless, the ability to move the head and change the camera accordingly, which does transmit an insider sensation, makes the overall experience unique in terms of immersion feeling, when compared with regular screens.

The interaction in the immersive environment involves user movement, light fixture selection and aiming - e.g. *select and aim different spotlights to the elements of a rock band and preview the results from several perspectives* - user tests in Chapter 4. By using the SpacePoint, the user can do **light editing** or **user movement**.

In light editing, aiming or position changing, the SpacePoint is used as a pointer controlling a cursor drawn in the scene for the three tasks - different cursor models for each task, explained in Section 3.7. The cursor position is obtained by shooting a raycast (Figure 3.5) from an invisible object, coupled with the user's position. This object represents the SpacePoint in VRLight, since its orientation is read form the real device. With the SpacePoint's forward vector direction, the ray is shot and, in the hit point, the cursor is drawn. By default, the device's zero orientation is to the North, meaning that if the user is sitting facing South, the cursor is still pointing North when the program starts. To correct this issue, a calibration is automatically made by adding the needed rotation to the SpacePoint object, every time a cursor is needed (Figure 3.6).

[1]Z800 3D Vision - www.3dvisor.com

Figure 3.5: Cursor obtained by shooting a raycast.

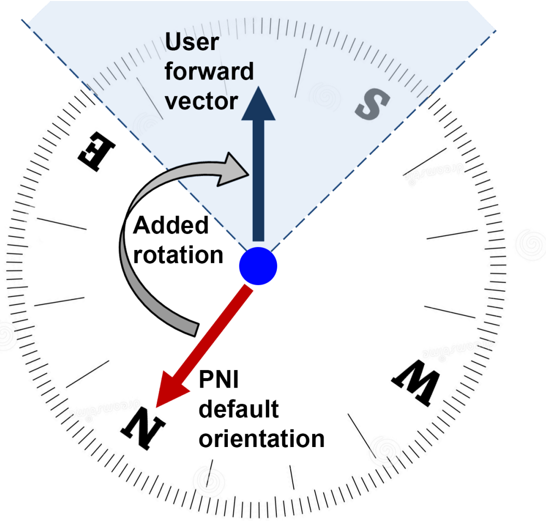

Figure 3.6: SpacePoint calibration.

The Nintendo Wiimote is also an option, although less accurate. Tests were made with the basic remote and the infrared sensor-bar, which limited the interaction to the area where the remote could detect it. Also, the controller's sensitivity is too high by default, which limited the cursors stability, making the hit-rate in the menu buttons very low. The SpacePoint, although connecting via USB cable vs. Wiimote's bluetooth, showed higher stability. With great improvement in the hit-rate, SpacePoint also provides the roll axis, thanks to the gyroscope, which the Nintendo Wiimote only provided in the upgraded version - the Motion Plus - not available during the development.

3.4 Connection to external light controllers

Light control in show business is the process of changing the light behavior, depending on several factors such as the course of a theater scene or music animation. Regarding the thousands of hardware and software options available for light control nowadays, which may depend on light technicians' preference or the scenery's complexity, our prototype soon showed the need to accept the universal communication system for light control - DMX, the standard protocol in stage lighting and effects.

Nowadays, DMX can be used to control both real and virtual lighting rigs (Figure 3.7) which opened up new possibilities for software applications. Virtual consoles are now an option for light control and the design and preview tasks can now be supported by the chosen hardware or software to be used further in the shows.

3.4.1 DMX-512

Before focusing on light controllers and the stage design process, it is important to understand how DMX works in pro lighting nowadays. A light fixture contains one or more controllable parameters, all listening to a **different**, but **consecutive** DMX channel. The only thing that can be setup in the light equipment

Figure 3.7: DMX communication.

is the **first channel** to be reading from - which will control the first light function. The fixture will then assume the next channels to the following parameters. It is not possible to designate each parameter's channel. This way, if channel **10** is set as the first to be reading from and the light has five controllable channels, this fixture will be controlled by channels 10, 11, 12, 13 and 14. Figure 3.8 illustrates a typical DMX packet being read by three fixtures, with starting channels 0, 5 and 10, respectively. In general, light consoles' leftmost channel is the zero channel.

In VRLight, when adding or editing a light fixture, the user can also select the first channel to be reading from. In the light editing menu - detailed further in Section 3.7.3 - in spite of choosing only one channel, the label output always shows the first and last channels to inform how many parameters control each fixture - e.g. from the previous example, if selecting channel 10 as the first for that equipment, the menu will display the label: **10-14**. A channel increment or decrement will be shown as **9-13** or **11-15** respectively.

Addressing the DMX communication in a pre-visualization software is essential for console labeling or cues programming, for example. When previewing the real show, if the technician may use its real device, the fixture's channels must be the final ones, so that the entire pre-visualization task makes sense. By respecting this rule, the technician only needs to arrive at the venue, match VRLight's fixture

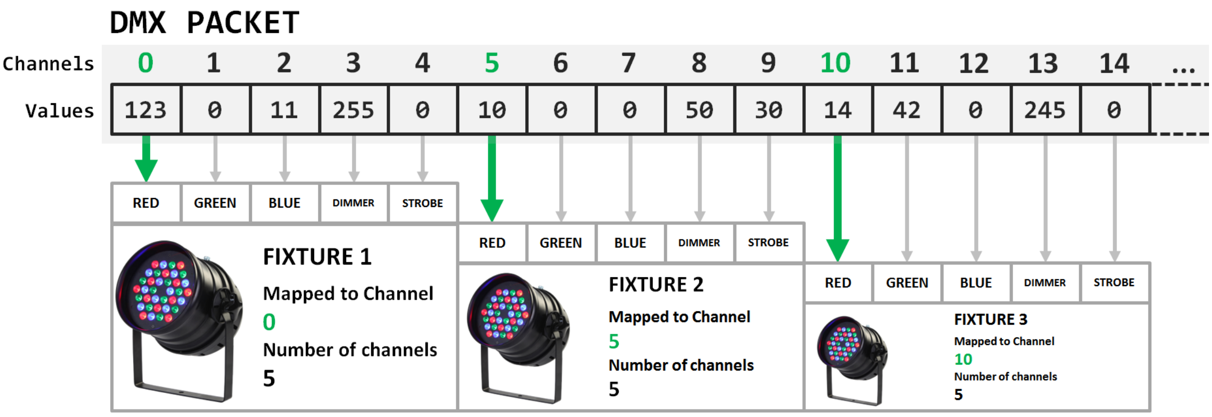

Figure 3.8: DMX packet and fixtures channel mapping.

channels with the real units' channels - using the *config* file - and the final show will match VRLight's output. This is one of the most convenient features for stage light design, since the usual stress prior to an event is reduced with the entire DMX mapping being setup before the show.

3.4.2 DMX input to VRLight

The input module accepts any DMX device by relying on the Art-Net protocol for transmitting DMX messages over UDP. This option is what enables the show design team to use its favorite device for light control testing. Light consoles or any other hardware or software device communicating with VRLight are ready to control virtual lights in the scene.

The Art-Net protocol is a simple implementation of the DMX-512 protocol over UDP, in which packets containing lighting settings are transmitted over IP packets, typically on a private local area network. It was made available as a software development kit (SDK) and allows software controllers to take place in stage lighting. Two way communication is provided, enabling virtual controllers to send DMX messages to both hardware (light fixtures) and software (pre-visualization tools), as well as light consoles to control virtual environments (Figure 3.9). In VRLight, an observer pattern was used to track an Art-Net listener. Any DMX packets being broadcasted to an IP address of the user's choice are caught in the software. The array containing integer values for each DMX channel (0-255) is then interpreted by the core engine and sent to any virtual lights listening to the DMX channels. This behavior is all handled in the **DMXReceiver** script, which starts with the application and waits any DMX input to be sent to the light fixtures.

If using the broadcast IP (255.255.255.255), the same DMX messages being read by VRLight can simultaneously be sent to real fixtures listening to the same channels. Figure 3.10 shows the same

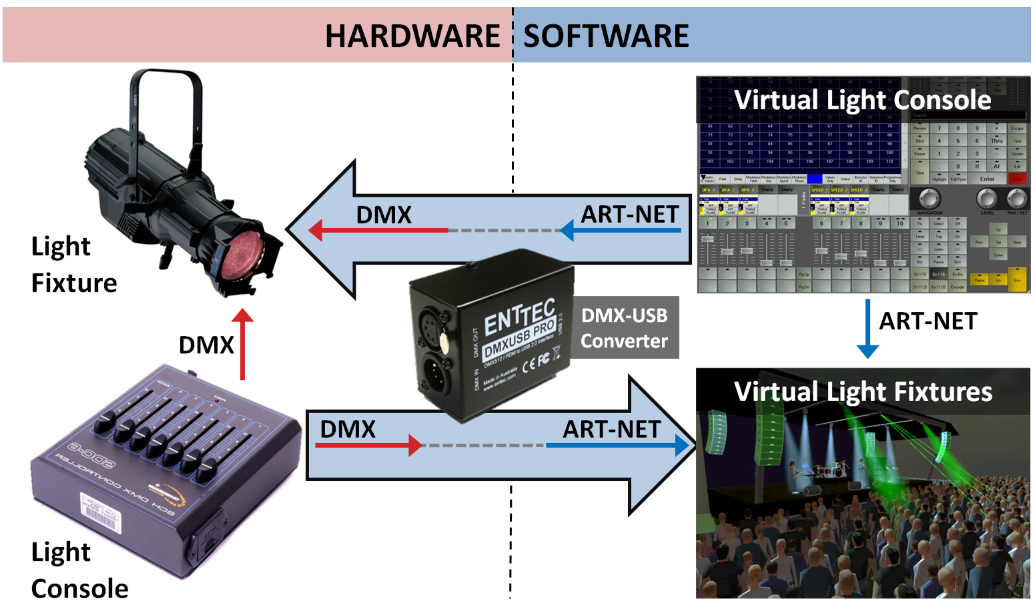

Figure 3.9: Communication options using DMX and Art-Net.

light output in both hardware and software lights, controlled by the same light console. The visualization platform is, in this case, the technician's monitor. The director can do all the light design at the same time.

For testing purposes, only DMX software was available to control the lighting in VRLight - **DMXControl**[2] was the chosen controller. Although, to help the technician with the fader controls, two extra hardware tools were added to the setup - one iPad tablet with TouchOSC[3] app and a Korg Nanokontrol[4]. Both this solutions use the MIDI protocol for communicating with the DMXControl software, but the input to VRLight is always DMX. The use of MIDI was only to support the technician's task by providing easier access to the DMX channels which were hard to control via mouse in DMXControl.

3.5 Real time light control

During light design, the ability to perform light changes to obtain feedback is a big advantage. This feature is even more interesting if both design and control are made at the same time. With real-time lighting preview, the director can confirm the final behavior while selecting a fixture's position or aiming a spotlight.

In VRLight, real-time light control is achieved by reading external DMX inputs into the scene. Lights being inserted in the environment are automatically fetching data from the DMXReceiver. The script stays active during the whole interaction, ensuring that even in light editing mode, the light technician can send any DMX input to the scene, if asked by the director. With this ability, the design can carry on without regular stops to preview lighting behaviors in the current positions or settings. This option removes any independent processes for light editing or preview, since they all run at the same time.

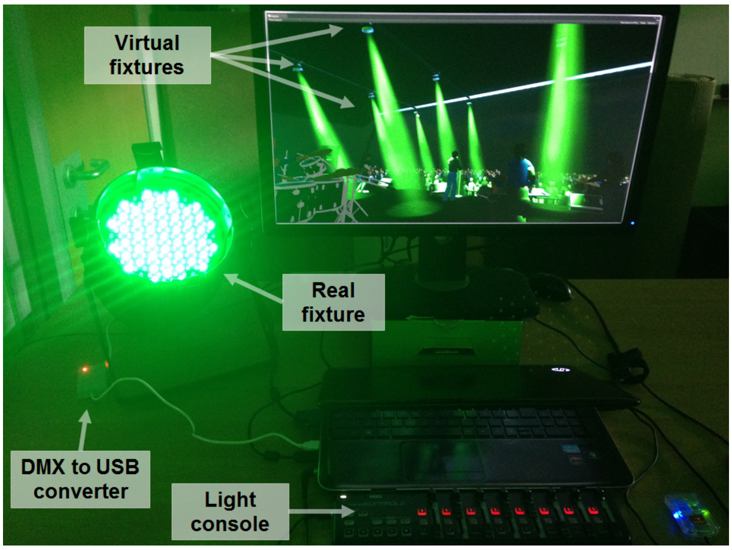

Figure 3.10: VRLight working with same DMX input to real and virtual fixtures.

[2]DMXControl - http://www.dmxcontrol.org
[3]TouchOSC - http://hexler.net/software/touchosc
[4]Korg Nano - http://www.korg.com/us/products/controllers/nanokontrol2

3.6 Virtual stage environment

VRLight works with pre-modeled sceneries - theater, tv set, nightclub, bar, etc - and provides a variety of stage light fixtures to be installed in the virtual venue. In order to better demonstrate the results of our work, we had the chance to contact a theater lighting specialists team in Lisbon, which offered their stage to be a possible model for VRLight tests. Unfortunately, such arrangement could not be done due to the team's heavy schedule. The model ended up staying as initially planned - a concert stage with a simple lighting structure. However, the final model ended up being appropriate to demonstrate all the prototype features with success. Our proposal to test VRLight in a real scenery is still standing to this day.

For prototyping purposes, the stage model was thought to be simple and intuitive for the user, not disregarding the realistic features. It consists in an open-air structure with three central bars (metal cylinders) for light fixtures, representing the usual stage lighting truss. This trust model was avoided since first tests with the Oculus Rift's resolution showed two limitations: from the low pixel number per eye screen, slim objects like the structure bars suffered big aliasing that even with 8x anti-aliasing filter looked jagged. The second issues came from the high number of triangles resulting from a structure of that type, plus the anti-aliasing effort to add detail to such face numbers. The headset could not deliver over 10 FPS with this structure, a number under the acceptable (aprox. 30 FPS), which lead to the model simplification showed in Figure 3.11.

On the stage floor, a rock band stands over the wooden texture to serve as an example model of a show demanding appropriate lighting. The initial environment shall contain this and every asset of the final show so, with all the models placed, lighting will be the only concern for the light designer. To complete the environment, other common elements were added to provide the most realistic feeling. The crowd facing the stage can provide light feedback such as how light illuminates the audience (Figure 3.12) how long should some lights be pointed to the audience to avoid visual impairment during and following exposure, or even, how would it be the light show seen from the center of the crowd. The model is finally enriched with other typical elements such as speaker arrays, stage monitor speakers

Figure 3.11: VRLight's stage model.

Figure 3.12: Light influence in crowd.

and crowd barriers. All these assets will diffuse and/or reflect the light, making them essential to a successful design.

VRLight's pre-modeled stage allows light fixtures in nine predefined positions, called **slots**. A slot is the parent object of the light fixture. When selecting new equipment in the light editing menu - explained in Section 3.7.3 - a new instance of the fixture object is added as a slot child, and the slot stores all related options, such as the light editing menu and data for the corresponding fixture. In this prototype, each of the structure's central bars contains three slots. This limited number became definitive when in attempts to add more than nine slots. Although the attention had in the stage model and assets design, the Oculus Rift did not provide the enough FPS necessary to run the software smoothly. Too many lights running at the same time started slowing down the whole visualization, which lead to a slot limitation. Ideally, there should be as many slots as empty space in the structure, which is definitely the future work ahead of this project. Nevertheless, the resulting prototype provides a decent workspace to demonstrate the immersive pre-visualization advantages in stage light design.

3.7 Light design

Stage lighting has endless fixture options nowadays. From light projectors to lasers, with single behavior or multiple effects, there is a solution to almost any design need. Our prototype contains a short but representative group of light models ready to be used but, regarding the countless options, it is scalable, accepting new fixtures in a very easy process. In this Section we detail every aspect of light editing in VRLight, which virtual light equipment is included and the process of adding more fixtures if needed to future light design projects.

3.7.1 VRLight's fixtures

VRLight has five different light fixtures chosen to represent the main lighting solutions available nowadays. These five models, detailed in Appendix B, represent a small group of options in stage lighting,

Figure 3.13: VRLight's fixtures.

but the most used types in show business. Therefore, during implementation, although following specific manufacturer's models and manuals, some fixture's names were generalized to represent common types like Par cans or Lasers. The 3D models were obtained at Google Warehouse[5] and imported to Unity3D.

The VRLight's fixture models, labeled in Figure 3.13, are the Par Can, Strobe, Laser, Gobo[6] and Moving Head. These five fixtures represent different types of solutions used in stage lighting nowadays. They cover light effects such as flat light beams, strobing lights, lasers and shaped or moving beams.

Regarding the visual feedback for each luminaire, different approaches were taken, depending on the unit. Fixtures containing defined light beams - Par LED, Gobo Projector and Mac 250 were developed using volumetric light shaders to create the light beam effect. An animated texture adds the smoke/fog animation which helps turning the beam visible. Changing at a constant speed, the texture creates the wind effect on the smoke hit by the beam, adding realism to the visualization. Color, strobing and intensity effects were addressed accessing the fixture's light materials and changing them according to the DMX value read from the DMXReceiver script.

Special cases like the strobe or laser lights had other implementations using very thin colored cylinders for the laser beams and Unity's spot and point light tools for the flashing strobe. The Super Laser 200 and Mac 250's movements were set to random for prototyping purposes. The required DMX channels for both fixtures were reduced in order to demonstrate the essential behavior of the luminaires only. With some lights requiring over 70 DMX channels to control all their functions (colors, pan, tilt, strobe, dimmer, macros, special effects, etc.), some simplifications were mandatory in order to test the prototype without an highly complex development, which would not bring big advantages to what is to be evidenced - pre-visualization in an immersive environment.

VRLight contains five fixtures in this prototype but is ready to accept new ones in a quick and easy process. Scalability was automatically required when looking at the countless possibilities in stage lighting

[5]Google Warehouse - https://3dwarehouse.sketchup.com/

[6]Gobo - derived from "Go Between" or "Goes Before Optics", contains physical templates slotted inside the lighting source, used to control the shape of emitted light.

equipment. Therefore, VRLight supports new units by simply adding the 3D model, materials, behavior script and textures to the resources folder. All this data, together with a Unity3D Prefab file, which links all the information, is interpreted by the software and stays automatically available to use in the virtual environment.

3.7.2 Behavior scripts

Stage lighting is a massive industry, delivering countless solutions to every type of light show. Each equipment has its unique behavior for the DMX channels it reads. Even similar models from different manufacturers may only differ in which channel controls some parameter. This way, programming a virtual fixture's behavior is an isolated process that will only work for that same model. In VRLight, this development stage was based in some specific brands. However, it is intended to demonstrate the fixture's main purpose, disregarding specific configurations that expert users may find missing in some equipment.

Each virtual fixture contains a script attached and runs for as long as the equipment is installed in a structure slot. The script contains all the information needed to provide the unit's behavior, translating DMX values in virtual lighting action. At every program cycle, if a new DMX input is received in the DMXReceiver, all the light parameters are updated by the script. These can be **colors**, **strobing**, **dimmers**, **movement macros** or **gobo changes**. To avoid endless unnecessary readings to check for new values, if a packet is received in the DMXReceiver, it notifies all the fixture's scripts to update their values.

3.7.3 Light editing menu

Each slot in the structure contains a menu with the necessary information and options for fixture choosing, channel selection and light aiming. This simple menu is called by left clicking the SpacePoint device and selecting the corresponding blue sphere attached to the desired slot.

Before any sphere is selected, the director can see two labels attached to each one, containing the slot number and the DMX channel that the corresponding light fixture is reading from (Figure 3.14). The spheres will open the menu if clicked but can be used only to provide that information at first. If the director needs a light parameter change on *Slot 1*, he can ask the technician by demanding some console action on the matching DMX channel provided by the sphere label. This option avoids unnecessary clicks to open the menu and a faster information acquaintance for communication between designer and light technician. If pointing to a sphere, the same is highlighted by scaling and color intensification. The remaining ones go the exact opposite, highlighting the desired information and target.

When a sphere is clicked, the corresponding light editing menu is opened. A smooth animation scales it from zero to its final size, making it seem like it is growing from the fixture. Also, at the same time, the

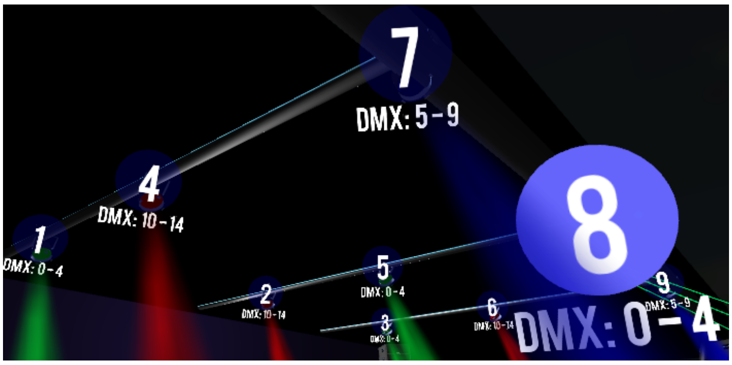

Figure 3.14: Light editing slot spheres.

menu travels and faces towards the user's position. The menu, illustrated Figure 3.15, is then ready to be used.

A simple interface is provided in the light editing menu. With very few options, the susceptible lack of editable features is due to the DMX protocol, responsible for all fixture's behaviors in pro lighting. This way, any light parameter other than aiming - how the equipment is installed in the structure to point in certain direction - is controlled in the console. The menu ended up needing only six buttons for three main sections - **fixture selection**, **light aiming** and **menu closing**.

The first section is the **fixture selection** billboard, under the menu title containing the root slot name. It allows to choose between the virtual equipment available using the black buttons on top and bottom of the white board. Scrolling through the list will display the name and photo of the fixture and, on the right, the DMX channels to be reading from. The channels field can be incremented or decremented to set the desired values. The two numbers represent the first and last channel of that fixture, as explained in Section 3.4.

Figure 3.15: Light editing menu.

Next, the **Aim Light** button enables a new cursor, similar to a shooting target, as a metaphor for where the light will shoot its beam. Together with the cursor, the corresponding fixture's light beam(s) will follow where the user is pointing in the scenery (Figure 3.16). Because director and technician are working together in the stage setup, a simple request from the director to have light coming from the equipment will help in the aiming task. Without light, the fixture's direction can still be changed but, using the cursor only, which does not provide the same feedback only.

In several environments, clicking outside the menu to close it is a common feature. Due to possible misses in the menu buttons, in VRLight's light editing case, this feature was replaced by a **close button** at the bottom. Informal tests revealed it is more time consuming to restore the menu and keep the on-going task if a button miss closes the menu accidentally. Therefore, when done with editing one light fixture, the user just has to click the close button at the bottom of the menu. After editing a light fixture's settings, the user may want to proceed to another slot or close the light editing mode. Closing the menu will replace the spheres to allow less clicks to get to another slot. Clicking anywhere else removes the spheres and the editing is done.

3.8 User movement

One of the most important pre-visualization goals in every industry is to provide as many preview angles as possible. Enabling total control from which position to look to an object, drawing, lighting environment or any other is the key to a successful preview. In VRLight, since user immersion lets the designer step into the virtual environment with an headset to look in every direction, it was crucial to allow full movement inside the scene. SpacePoint device was the solution.

There are two main options to move inside VRLight - the **Change Position Menu** and **Joystick Mode**. To help the user feel the immersion and know the correct forward orientation during movement, two arms were added to the user's position, both pointing to the front. User tests were carried out and determined

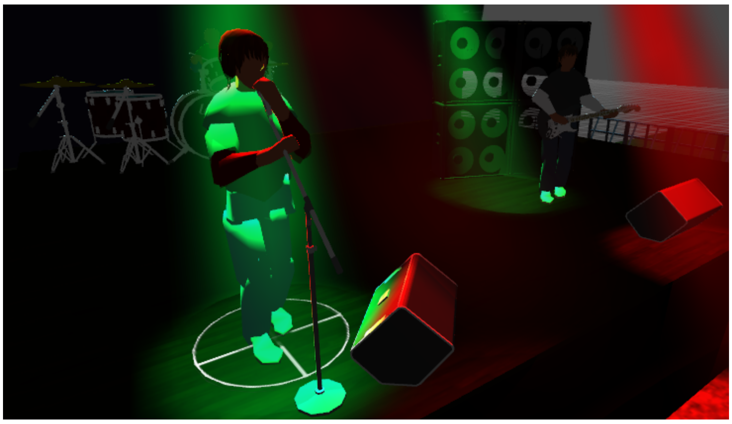

Figure 3.16: Aiming a light fixture to the singer.

Figure 3.17: Change position menu.

the need to keep the two distinct movement options, explained next. Test results are detailed in the Chapter 4.

3.8.1 Change Position Menu

Using the SpacePoint device, the Change Position Menu is accessed by clicking the right button and closed by clicking anywhere outside of it with any button. This menu (Figure 3.17) is split in two sub-menus. The left menu - **Movement** - contains three movement options to choose the user's exact location, rotation or height. The right menu - **Go To** - provides predefined positions which will move and rotate the user to the exact named location - Stage, Behind Crowd and Previous Position.

In the Movement menu (left side), the **Point and Go** button activates a *point to where he wants to go* mode, also studied by Cabral et al [33]. The SpacePoint cursor model is replaced with a 3D human stick standing on a blue disc with an arrow attached, as illustrated in Figure 3.18. This model represents the user and its next location and orientation. Also, the user's height is increased to allow a better view over the scenery and increase pointing precision. The diagram in Figure 3.19 shows all steps involved in this method.

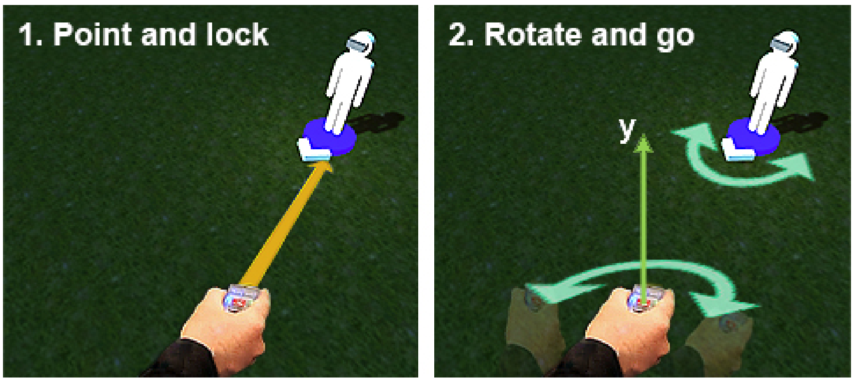

Figure 3.18: Point and go process.

Point and go enables a precise and intuitive movement, much different from the regular options - e.g.

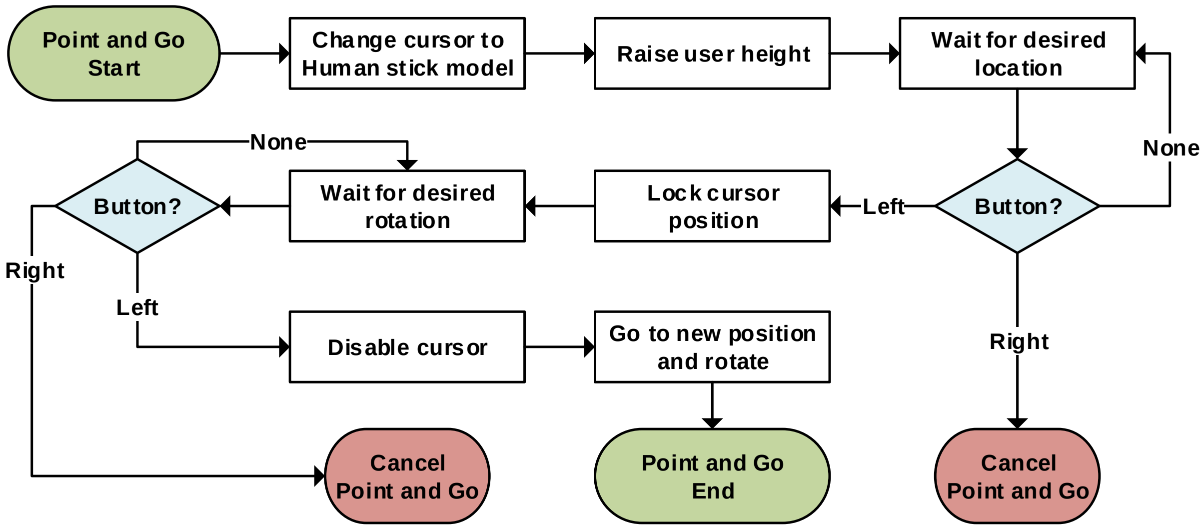

Figure 3.19: Point and go flowchart.

keyboard, mouse, joystick, etc. The main issue involved in this development stage was to deliver a smooth displacement from one point to another, to prevent motion sickness. Using Unity3D's iTween package, the MoveTo function was able to receive a soft acceleration and deceleration parameter which solved the nausea problem and added even more realism to the movement.

The next menu option is **Rotate**, which allows user rotation around its Y-axis. This was solved using the same SpacePoint axis rotation. After clicking the Rotate button, slightly rotating the SpacePoint will change the user's orientation as if a body rotation was happening - the virtual arms attached to the user's body will also rotate to achieve that same feeling.

Finally in the left menu side, **View Height** changes the user's height. This feature helps the user acquire a top view of the show, that could help understand how it would be seen by television cameras, for example. Also, for editing purposes, specially in light aiming, the majority of users testing this feature confirmed the importance of this option (Section 4.3.2). Pitching the SpacePoint up or down in View Height mode will raise or lower the user at a slow and sickness free speed. Although, at some point, immersion can make users feel some dizziness. Figure 3.20 demonstrates the use of the SpacePoint to change height.

This movement menu provides a set of options to change position or orientation in the scenery to an exact location, rotation or height, or by predefined positions. Next, the Joystick Mode provides an alternative displacement approach to access any part of the environment.

Figure 3.20: Changing view height.

3.8.2 Joystick Mode

The Joystick Mode was the first movement approach tested in our prototype and is based in the typical joystick hardware interaction. The three SpacePoint's axis (Figure 3.21) are used to move (X - forward or backwards and Z - left or right) or rotate (Y - left or right) the user. Holding the right button, starts the Joystick Mode and registers the device's orientation at the click moment. Calculating the difference between all further SpacePoint orientations and the first one provides the speed values in all directions and the user position is changed accordingly. The diagram in Figure 3.22 illustrates all the steps involved in this method.

In first tests, this approach showed some limitations that are not found in regular joysticks. Being the SpacePoint hold in the hand, the intention to rotate and move forward at the same time accidentally lead to undesired Z rotation, caused by thoughtless arm or hand movement. Any other two axis combined always driven the user out of the desired path, due to the unwanted use of the third axis. With a regular joystick, the user can feel each axis by having to apply little force to move in a certain direction. The SpacePoint otherwise, works as a remote, weighting less than 30g and without any force feedback to manage the axis rotations.

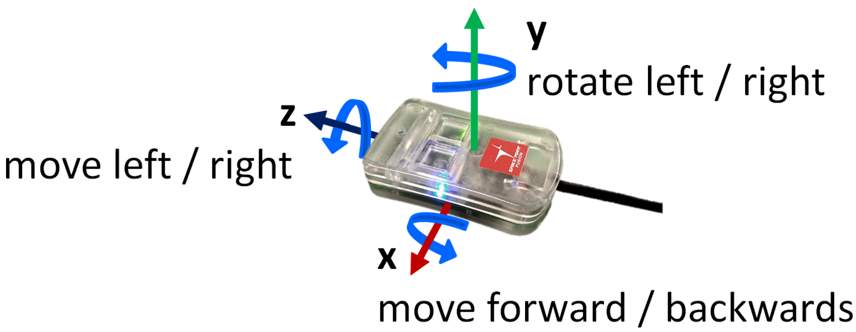

Figure 3.21: SpacePoint axis rotation.

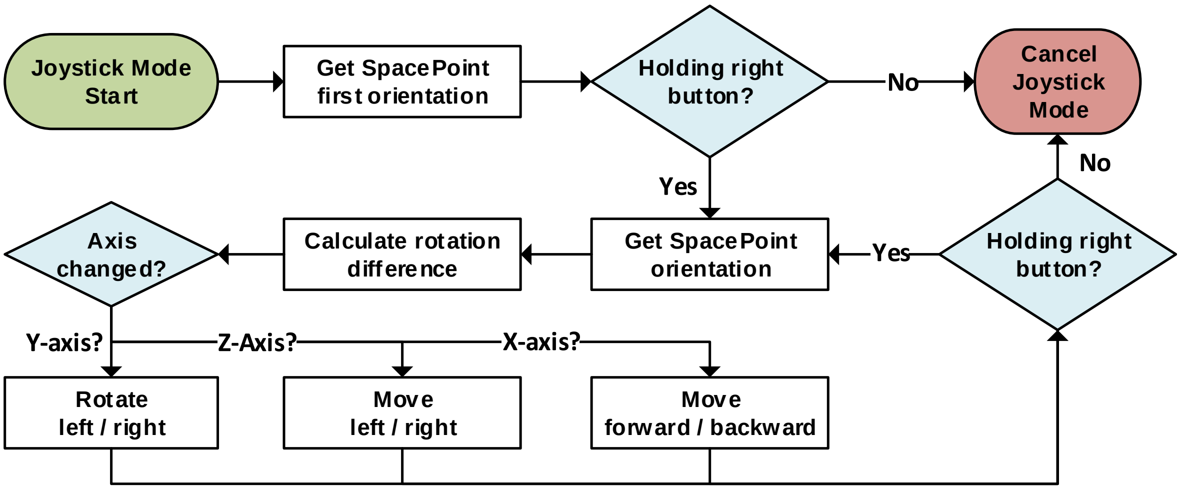

Figure 3.22: Joystick Mode flowchart.

This option was not discarded since the point and go method - explained in the previous Section - is not ideal for very short movements - e.g. *drummer is obstructing the view and only half a meter to the left is necessary to solve the problem*. With the point and go approach, the user would have to look and point to the ground, half a meter to his left and be very precise in choosing the correct location to avoid new obstacles. In Joystick Mode, a slight left rotation in the Z-axis to his left and the user starts moving to the left until the button is released. Less steps are involved and the feedback while moving allows to choose the exact position and stop anytime by releasing the joystick button.

Considering the pros and cons of this movement approach, user tests were carried out, described in Chapter 4, to determine the need for such option. Users with previous joystick experience agreed in leaving this option available. Some tests were even complete using this mode only, although the limitations.

3.9 VRLight prototype

VRLight combines new ways of interacting in light design, with the immersive feel making it a unique project in stage lighting pre-visualization. The challenge of combining all the technologies and methods described in this Chapter in a single application resulted in a new way of real-time designing and previewing a light show, without complex interfaces or any specific skills. Figure 3.23 illustrates the final setup in action, similar to the concept presented in Section 3.1. The director immerses in the environment using the HMD and holds the gesture-based interaction device to perform stage design and movement inside the scene. The light technician controls the lighting rig through an iPad which, although covered by the preview monitor, is connected to the DMX software running in VRLight's machine.

The use of an head-mounted display in such environment provides a unique overview of the lighting performance. With the option to look anywhere in the scenery using his head, the user now takes the

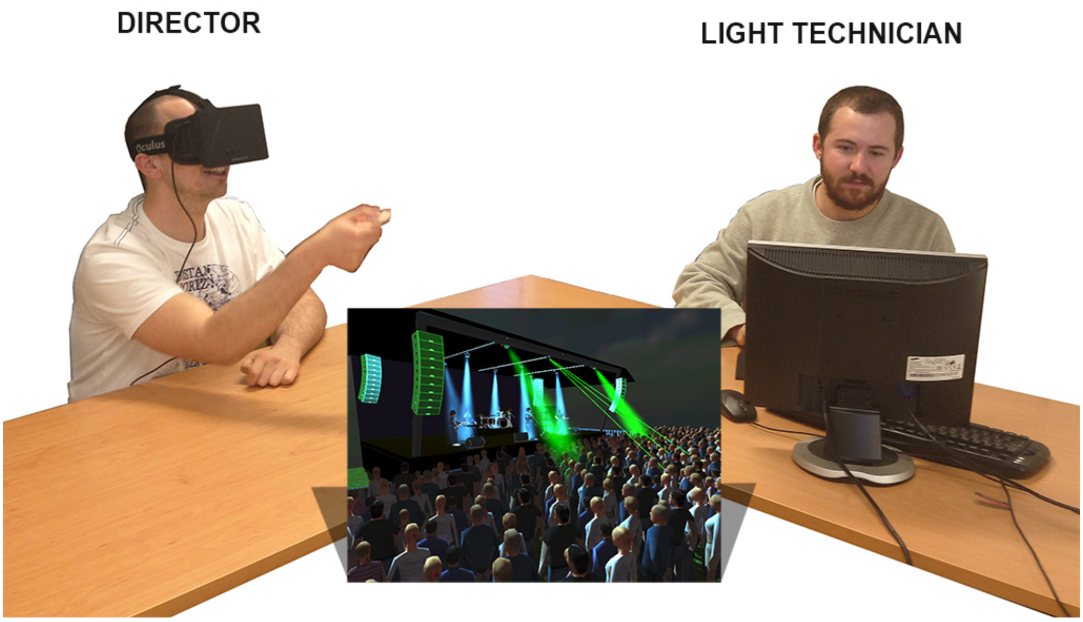

Figure 3.23: VRLight interaction.

advantage of feeling inside the environment and preview the show as if it was really happening. Although the resolution limitations of the Oculus Rift, the level of realism enables a single virtual reality solution for lighting simulation, that will only benefit from the HMD evolution. The new Rift headset, released this year but with big waiting lists for its delivery, will add image definition and improve the overall experience with the full high-definition settings.

Having in mind the endless stage configurations and the lighting equipment options available, our prototype soon assumed a scalable approach during the development, making sure to deliver an easy way of importing stage models or upgrading the fixture list in a quick process. In light equipment, it exposes 5 types of very well-known luminaires in stage lighting industry, ready to be used in any modeled scene imported to the software. Supporting any stage and fixture models in our prototype makes VRLight a continuously growing tool, adaptable to any demand.

In what light control is concerned, this prototype joins the best of hardware and software options with the DMX-512 protocol being fully supported. The technicians favorite console can be used to manage the show, thanks to the Art-Net communication, delivering DMX packets over UDP to VRLight, whilst ensuring the same console and channel mappings for both pre-visualization and final performance.

As for interaction, light editing alongside with user movement were addressed with the small but powerful Space Fusion device, a gesture-based interface for pointer interaction. With easy access to menus and different movement options like the point and go or joystick modes, the user handles the device in his hand to carry out all tasks without having to look at it. The simple two button interface was programmed and calibrated to ensure the fastest workflow, as tests show in the next Chapter.

3.10 Summary

In this Chapter, we have presented the solution developed in order to test our approach. VRLight is a virtual reality solution for lighting simulation in events. Immersive pre-visualization with easy post-WIMP interaction were the main goals of this prototype, which delivers a new stage design collaborative approach with simple and more defined tasks for each user, increasing focus and creativity on both sides of the event preparation. Aiming to reduce the learning efforts, with minimalistic menus, easy and intuitive *point and go* movement inside the scene, as well as other useful features such as view height definition or predefined positions, VRLight can be a new step in event pre-visualization.

Keeping the best of existing technology studied in the previous Chapter, VRLight follows recent applications and allows the use of any light console for control, as long as it relies on the standard light control protocol - DMX. This way, our prototype does not expose any limitations to the technicians' console preferences, making it a viable solution for any type of stage and event. On the other hand, the director can only focus on the design task, supported by the technician who receives requests and provides real-time lighting changes to the scene. Inside the environment, the director experiences an insider feeling, previewing from any position, using the SpacePoint to travel in the scenery and his/her head to change the camera accordingly, as if watching the live show in real-time.

User tests were carried out to validate our approach to stage design and lighting pre-visualization. With big focus on simplicity and no learning skills prior to the evaluation, VRLight's testers showed great proficiency in completing the tasks to which they were subjected. Although the difficulties in finding expert light technicians and directors, the overall interaction evaluation showed good results, as shown in the next Chapter.

Chapter 4

Validation

In order to validate our proposal, it was necessary to conduct a set of user tests. VRLight was developed for stage lighting purposes so, light designers and technicians would be the ideal expert group to validate our prototype. Before starting the development, we had the chance to meet a theatre lighting experts group, who showed great interest in shifting from regular screens to an HMD solution. Unfortunately, after initial talks, the team's schedule did not allow any more meetings, which reduced the possibilities to test with real experts in the lighting business. From the final user group who evaluated the prototype, only two light technicians from a theatre and nightclub were included in VRLight's validation.

Despite the importance of lighting experts participation, VRLight exposes new interaction paradigms suitable to be tested by anyone. Validating with non-experts could demonstrate how simple can the interaction be, even without any knowledge in this field. As for validation against existing tools, such tests could not be done in time and VRLight, being a first prototype with big focus on immersion and interaction, is far from the complexity and learning effort required by the commercial software available. This validation was set as the future work in VRLight's development.

The tests were structured in two stages: three interaction tasks in VRLight's environment, followed by a post-questionnaire to rate the prototype's ease of use, and a comments section for optional written suggestions. Due to the low number of lighting experts, a preliminary introduction to stage lighting design and DMX was given to all the participants. This Chapter covers the testing setup, user profile, tasks validated, experimental results and summary.

4.1 Testing setup and user profile

Tests were conducted in a closed environment at the Instituto Superior Técnico in the Taguspark campus. A single laptop computer was used with VRLight for visualization and interaction, together with DMXControl as an external light console software to send DMX inputs to the virtual lighting rig. The computer specifications included a 2 GHz Intel Core i7-2630QM processor, 8GB DDR3 ram memory and an AMD Radeon HD 6770M (2GB GDDR5 dedicated) video graphics card.

For visualization, an Oculus Rift headset was ready for the user's tasks as show directors/designers, and an external monitor outputted the technician's view, with this control task being carried out by our group. User interaction was made through the SpacePoint Fusion controller and the light control using an iPad running TouchOSC mapped to DMXControl, ensuring the light feedback in the scene. Figure 4.1 illustrates the setup described during a user test. On the left side, the user interacts in the immersive environment using the headset and gesture-based interface, connected to the laptop computer running VRLight. On the right, a member of our group supported the visualization by providing real-time lighting control using the iPad. Using the external monitor, the technician could follow the user interaction during the tests and obtain feedback from his own lighting changes. To explain the DMX protocol, a Par 56 LED Projector supported the briefing stage.

A group of 20 users, aging from 18 to 40 and mostly male (70%) were present in the test stage. Only 25% had tried head-mounted displays before, all of them in Taguspark's development or testing environment. Regarding stage lighting knowledge, only two users (10%) had previous DMX experience but none of the participants ever used a stage lighting pre-visualization software before. In gesture-based interaction experience, 55% had tried at least SpacePoint, Wiimote or PS Move, and 90% used a joystick before.

Users' profile clearly demonstrates a small number of stage lighting knowledge in the group. Having in mind this possibility, a brief DMX introduction was given before each task, to ensure the same level of knowledge needed to understand the light editing menu. However, VRLight was developed with

Figure 4.1: Users in test session.

only DMX channel designation options for the designer working ”inside” the environment. All complex mappings, cueing and other technical aspects were done in the technician side, leaving users with the director's interaction tasks only.

4.2 Tasks description

Three main tasks were chosen to validate VRLight's capabilities for stage lighting design. These three tasks can be split for two different purposes: **user movement** - first task and **light editing** - second and third tasks. Before starting the tests, users were briefed on how DMX works and why does the first channel is the main concern in fixture channel settings - as explained in Section 3.4. This knowledge was important to complete task two - Section 4.2.2.

The briefing also included an explanation on the separate designer and technician tasks, ensuring that every user knows his/her role in this evaluation. After feeling comfortable with these topics, users were requested to put on the Oculus Rift headset and hold the SpacePoint in their hand. Already seeing the environment, one minute was given for each user to know and understand the menus and movement modes available in the prototype. The tasks were explained after the first minute of experiencing VRLight, without removing the headset.

4.2.1 Task 1 - User movement

After the first free minute to get used to the environment and interaction options, the first task could start. This first test covers user movement and, by analysis of the informal tests during the development, it would not help testing the Point and Go movement against Joystick mode due to this second's limitations mentioned in Section 3.8. This task involved moving the user to 4 pre-defined positions, using any of the movement options available - Point and Go, Joystick mode or both combined - and in the fastest time possible.

A yellow target with an arrow attached was put on the ground of the virtual environment, indicating the required position and orientation. If standing on top of the target facing the correct body orientation - with 30 degrees of margin to each side - the object would move to the next position. The task started from *Behind the Crowd* predefined position and ended when all four positions were visited by the user. The elapsed time was registered for each user. With the yellow target set to hide in strategic locations - e.g. crowd obstructing the direct view to the object - users needed to go through more than one movement options to complete the task in the shortest time possible. Those included changing the view height to search for the target, rotate via menu or joystick mode. Predefined positions were not allowed to use in this task. Figure 4.2 illustrates the target, the use of the *Point and Go* method to change position and the view from over the target with the correct orientation.

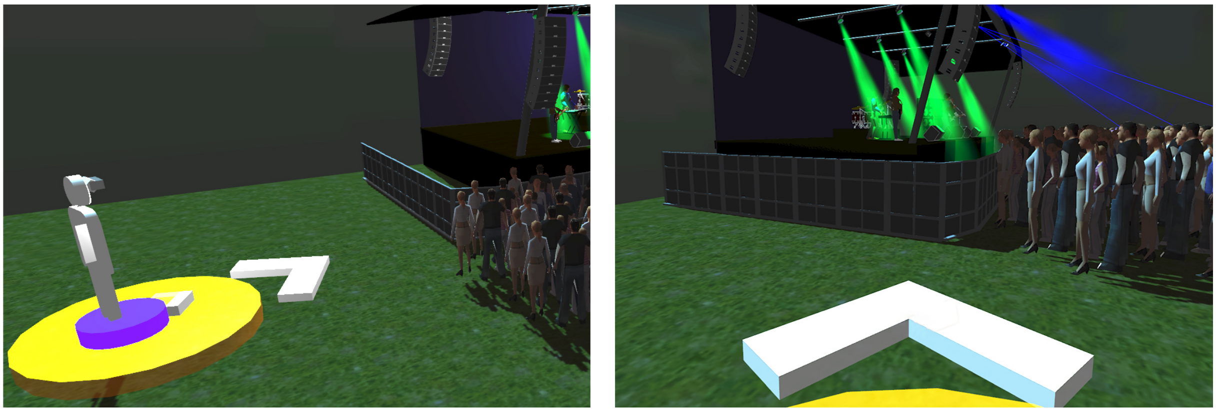

Figure 4.2: Task 1 - User selecting position over yellow target (left) and view from over the target with correct orientation (right).

As said before, any movement options were allowed in this task. Whether Point and Go, Joystick mode or both combined, users could use their favorite method. Curiously, users were divided in this preference. All pointed out the limitations in the Joystick mode but the fastest group were the users who used both techniques combined and two users did complete the task using only the Joystick mode, although the limitations. This task was evaluated with elapsed time results combined with which movement methods were used. Results are detailed in Section 4.3.

4.2.2 Task 2 - Adding light fixtures to an empty structure

The second task was created to validate the use of the light editing menu, specially the fixture picking section. Although this specific job is part of each one's creativity, being part of a timed test, the list of fixtures to add to each slot was previously defined to keep the exact same task to every user. The list was communicated during the test by a member of our group, to prevent users of memorizing the whole requested rig and lose focus on the task itself. The fixture list is presented in Table 4.1. Each of the table's rows was informed to the user after completing the previous one.

While adding the fixtures to each slot, users had feedback of the DMX inputs in VRLight. Figure 4.3 illustrates the stage before and after the task is complete. With the iPad, our team was responsible for controlling each channel. A specific color and strobing speed was set to the projectors to legitimate the use of real DMX to the virtual environment. The first three Par projectors in slots one two and three,

Slot number	Light fixture type	DMX channel
1, 2, 3	Par 56 LED Projector	0
4, 6	Par 56 LED Projector	5
5	Martin Atomic 3000 (Strobe)	9
7, 8, 9	Super Laser 200	0

Table 4.1: Fixtures to be added to the stage structure.

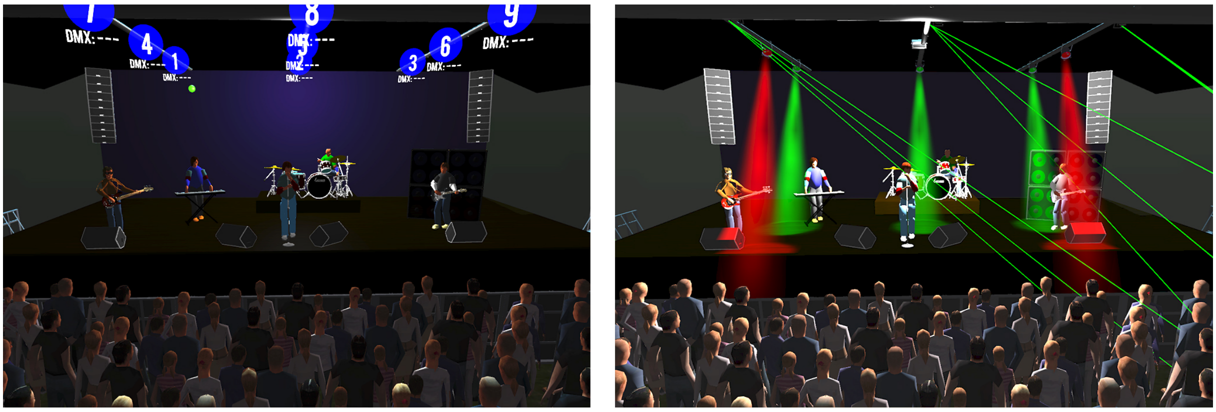

Figure 4.3: Task 2 - Before and after fixture selection.

had a constant green beam while projectors in slots four and six had a flashing red beam. The strobe in slot five flashed constantly, as it would be to expect from a fixture of this type, and the lasers in the remaining slots, also reading from channel zero, had the same color as the projectors reading from that same source.

Again, as in the last test, users started from the *Behind the Crowd* predefined position and were allowed to use any of the movement options provided, including predefined positions. The task's elapsed time was registered for each user.

4.2.3 Task 3 - Aiming lights to the band members

To complete the evaluation, light aiming task closed all the features available in VRLight. This test consisted in aiming nine Par LED projectors to the five members of the rock band standing on stage. With nine fixtures to five elements, users were allowed to choose which models would have more than one projector aimed to their position. However, no fixture could be forgotten, neither a band member could be left without illumination. Figure 4.4 shows the stage before and after the task is complete.

This task tested the aiming capabilities in VRLight, together with the user learnings in position selection

Figure 4.4: Task 3 - Before and after fixture aiming.

to solve the test. Coming from two tasks where movement was practiced, this last one, starting from *Behind the Crowd*, was impossible to solve from that same position. Since the aim target needs to be pointed to the stage floor, where the models are located, users needed to change position to a strategic location where aiming could be done with success. This task was evaluated via elapsed time.

Finished this task, users were requested to complete a questionnaire to evaluate VRLight's ease of use in the both user movement and light editing, provide feedback in terms of immersion feeling and realism settings, as well as give information about previous experience with stage lighting and the devices involved. A comments section was added to obtain suggestions or any other information users found relevant to VRLight prototype.

4.3 Experimental results

At the end of each user test, all execution times and questionnaire answers were recorded. Time values were analyzed and provided information about the prototype's capabilities in average time to complete tasks and best movement method. The questionnaire obtained user evaluation of the prototype's ease of use using Likert scales mostly.

Attempts to validate our prototype with other lighting pre-visualization software were not successful since the complexity was far off our learning possibilities in such short time and our prototype contains a small number of options when compared to the commercial tools available. Therefore, this Section only validates VRLight's capabilities in tasks completion with average time remaining as useful data for future comparison.

4.3.1 Task results

The three tasks were completed successfully by all of the participants in the tests. With all three tasks being complete in under three minutes each, results show VRLight's capabilities to perform simple stage design without great difficulty. Time values can't be compared with other applications yet.

In the movement task, the chosen method to perform this test was registered to validate which is the fastest option. Users could choose between using **Point and Go**, **Joystick mode** or **both** combined. Time results are charted in Figure 4.5.

Joystick mode alone shows the higher time to complete the task, as it would be to expect from its limitations. However, this value should not be considered, since it is from two users only, who preferred this approach although the limitations. The main focus goes to the Point and go method, when compared to its combination with the Joystick mode for slight position corrections. Users who used **both methods combined** did an average of 1:51, 21 seconds less than the average Point and go users.

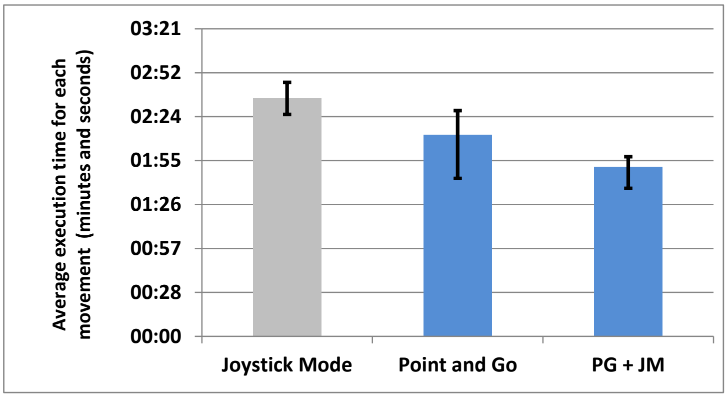

Figure 4.5: Movement task times using three different approaches.

Tasks two and three revealed the ease of use of our prototype in light fixture editing, with every user finishing the task in under 2:15 average. With nine slots to add or aim fixtures, these values may not represent much without comparing with other tools, but are significant enough to validate that each slot takes seconds to edit and all users were capable of finishing the tasks proposed.

4.3.2 Questionnaire results

In the questionnaire answered after the three tasks, users analyzed VRLight's features in terms of ease of use and importance to the interaction. To survey the users' favorite movement method, a five-point Likert scale was used to rate each approach in terms of ease of use. The Wilcoxon test was used to verify the statistically significant differences. Users strongly agreed that the **Point and go** method was the favorite of the two ($Z = -3.564$; $p = 0.000$). However, when questioned about combining the two approaches, 45% of the users agreed that both methods combined was the better option, confirming the advantage of using the Joystick mode for small location corrections. A text section was added for comments in both movement techniques and 40% of the inquiries suggested sensibility calibrations in the Joystick mode.

Still in user movement, it was asked about the **view height** and **predefined positions**' importance to the interaction in the prototype, using a four-point Likert scale. Results are charted in Figures 4.6 and 4.7. All users (100%) considered important (or very important) the existence of those features in VRLight. In a comments section for missing predefined positions, 15% suggested a "first row" position - first line of crowd next to the stage.

In the survey's light editing section, it was asked about how easy was to access the light fixture editing menu - by clicking the sphere corresponding to a slot - how easy was to hit the menu buttons and how easy was to aim a light to a desired position. With better results for the menu access and button hits, the four-point Licker scale (from difficult to very easy) used in the three questions revealed 90% and 75% very easy for menu access and menu button hits, respectively. None of the users classified the previous

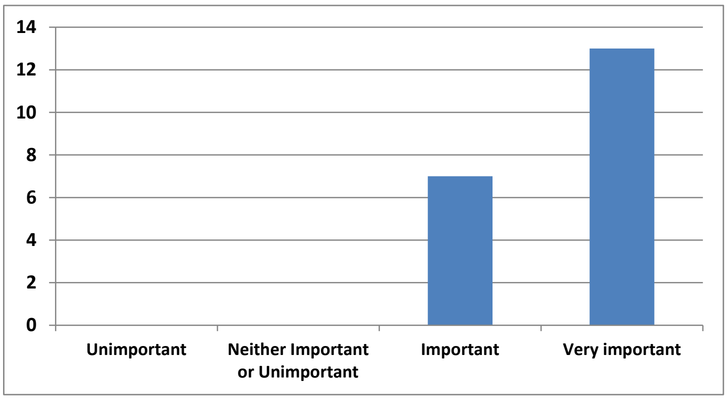

Figure 4.6: Changing view height importance to users.

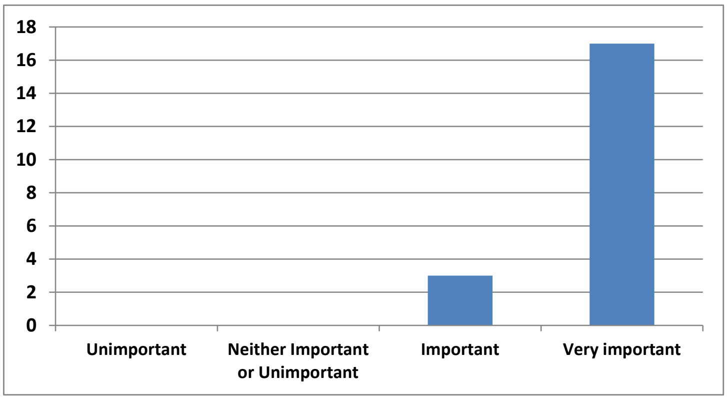

Figure 4.7: Predefined positions importance to users.

options as difficult. As for light aiming, some users (30%) considered the task difficult, mostly due to a bad location from where the user was aiming the fixture during the test. This was confirmed from the checkbox options in the following question, used to define the biggest issue that caused difficulty in the task.

The final comments section provided a few suggestions in what VRLight can improve. Some users proposed a solution in light the editing mode to switch directly to another slot without closing the menu. That option will avoid extra clicks and speed up the editing process. A few users suffered from motion sickness traveling from one position to another using the Point and go method. Slowing down the speed of movement in this mode will help but, the increased resolution in the upcoming Oculus Rift version will also be an advantage in the overall nausea issues.

4.4 Summary

VRLight is a prototype developed for stage lighting design and pre-visualization. The goals it was proposed to achieve were successfully validated in these user tests. Results may not have been compared with other tools, which is the main future work of this prototype, but all users completed the tasks and revealed great information about the prototype's capabilities. With a simple stage ready to be loaded with light equipment, all the participants were able to interact in the environment and achieve all the requested tasks. Also, regardless of missing the comparison with existing tools, this is the only solution that provides immersive visualization and the first to prove the capabilities to do stage lighting design in this type of virtual reality.

The three tests were focused in demonstrating VRLight's simplicity and, although elapsed times may not represent much now, they validate that the average editing time for each slot in the structure can be done within seconds. The interaction was also intuitive for users. From the analysis of the questionnaire results, users did find the Point and go movement approach easy and the menu interaction, with 6 buttons only, very easy to use.

By exposing new stage design interaction paradigms, suitable to be tested by anyone, our assumption was confirmed. Validating with all the participants, non-experts in stage design, demonstrated the ease of use of this prototype, even without any knowledge in this field. This results show the prototype's capabilities to perform stage lighting design tasks successfully, and in a way that, to the extent of our knowledge, was never tested before.

Chapter 5

Conclusions and Future Work

Immersive visualization and interaction is a relatively new option in virtual reality systems nowadays. Several industries still make use of WIMP interfaces on regular screens to do their design work. The advantages of stepping inside the virtual environment using new interaction paradigms is not yet a possibility in multiple design and pre-visualization solutions. Stage lighting simulation is one such case. Existing applications consist in powerful CAD modeling tools for stage design and impressive rendering systems for light visualization. Their appliances are getting huge in event lighting nowadays but the skills required to operate them are overwhelming. Interface complexity is a big obstacle to design and programming procedures and the previewing options remain optimized for regular computer screens only.

VRLight exposes an immersive virtual reality solution for lighting pre-visualization in events. This prototype introduces the head-mounted display for visualization and gesture-based devices for interaction in lighting simulation, which have never been tested before, and may represent an important step for designers and technicians in this field. On the other hand, this solution keeps the best of lighting technology available, by supporting the DMX communication protocol and a scalable approach, enabling easy addition of any new light fixture models to the software. VRLight accepts any type of light consoles, hardware or software, allowing the use of the final gear in the preview stage. Such advantage allows technicians to perform console programming while directors pick the best fixtures to the stage structure, all with real-time pre-visualization.

This solution relies on the communication between director and technician, with the complex control task being done by the technician in the console outside the virtual environment, supported by an external screen to preview the light behavior. Such approach increases creativity by unconcerning the director with complicated interface issues, leaving light fixture selection and aiming as the only focus in the design. Any light parameter changes are demanded by the director to the technician, who uses his console to send DMX inputs to the environment. Each task is separate, allowing bigger focus from both parts in their specific work.

On the interaction side, the reduced complexity in light editing and movement interfaces lets the user feel increased involvement in event production. The sense of being ”inside” the venue with the SpacePoint gesture-based device to move and edit light equipment with simple interfaces and tools raises stage lighting production to another level.

Aiming to achieve better interaction and immersive capabilities, when compared to the standard tools, we first proposed to test this prototype against existing software, with the help of expert lighting users. Our goal ended up being too complex to achieve with the time available. The unfortunate schedule limitations of our expert group, together with the complex commercial softwares available to test against VRLight changed our initial assumption. However, to validate VRLight's ease of use, it was challenging to test the non-experts capabilities to perform stage design tasks in our environment and impose that this prototype's simplicity should deliver an effortless virtual reality solution to perform stage lighting design and pre-visualization. The goal was achieved with all the participants in the user tests stage being able to finish the three proposed tasks. Our first objective of testing VRLight against existing tools is one of the future works set to this project.

In the prototype presented in this thesis, there are some aspects that, in spite of being the main focus of this work, are worth of improvements or could lead to interesting future work, such as:

- **Test the prototype in a real scenery**
  Having missed the opportunity to keep working with the theater lighting experts team, this initially projected test was postponed. However, VRLight is targeted to pre-visualize real environments, and such work is one of the major interests of our group.

- **Add more light fixture options**
  Although being scalable, VRLight can only improve by delivering more fixture options. The easy method developed to accept new fixtures will only require modeling the new equipment and programming its behavior to the DMX inputs.

- **No slot limit**
  This prototype showed some rendering limitations with the Oculus Rift headset, when testing with more than nine slots with active light fixtures. When using the computer monitor, there were no issues whatsoever. In the future, maybe with the new Rift headset, VRLight should accept unlimited fixture slots, as long as there is space in the structure. The development is also scalable here. Adding more objects of the type ”Slot” to the structure is the only requirement and VRLight will automatically recognise them.

- **Movable slots**
  With only nine slots, predefined positions were chosen to simplify the prototype. Slots are locked to their positions but, a simple pointer interaction to designate the slot position in the structure will provide more freedom in light editing, allowing to place light equipment anywhere in the structure.

- **Provide faster access to another slot when with menu open**
  As suggested by two users in the questionnaire, the light fixture editing menu should provide one-click access to the next or previous slot, to help in full structure loading situations. Keeping the spheres active may also be a solution, although it may bring a more complex issue with too much data being visible to the user at the same time. However, keeping the slot spheres could allow to click directly in another sphere to proceed with editing that slot.

- **Wireless gesture-based devices**
  The SpacePoint device enable an ultra precise pointer control in VRLight. However, its cable can not be seen by the user and may twist around the arm or body. Using the Nintendo Wiimote Motion Plus device, the bluetooth connection will remove this cable issue. This device was not available during the development, and tests with the standard Wiimote were done. The sensor-bar and sensibility limitations were responsible for switching to the SpacePoint.

- **Walk-in-place movement**
  New ways of moving inside an immersive environment using HMDs are emerging recently. The *Walk-in-place* approach [34, 35, 36] may bring a new level of freedom to the user, simplifying the overall interface and enabling real user movement, which increases the immersion feeling.

- **Compare VRLight with existing tools**
  The commercial software available delivers endless design options, with extremely complex methods to achieve little results. VRLight is a small but powerful prototype, although, it was not developed to compete in terms of number of features at this point of time. Testing against other tools, using the same model for immersion level comparison or simple light editing features was impossible with our solution. A good evaluation against existing software is the main future work of this prototype.

These functionalities raise a whole new set of challenges to be tackled in the future. VRLight can be the first step on immersive virtual reality for lighting simulation in events, improving actual technology available for stage design and pre-visualization.

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Appendix A

From design to pre-visualization

To have a stage drawing ready to send to the pre-visualization tool, the designer should go through the following basic steps in the CAD design:

- **Creating the performance space** — A project can be drawn from scratch using the CAD tools or it can be started by importing an existing drawing of the performance venue obtained from another source such as an architect or from the venue.
- **Defining classes and layers** — Before the stage, set, rigging, and lighting is drawn into the plot, it pays to organize the elements of the design according to classes and/or layers. Most CAD programs allow you to create layers, which are groups of items that can logically be placed together on a virtual sheet for the purpose of overlaying them in the drawing. Vectorworks is a CAD program that allows the creation of classes that can be used to group like elements of the design such as spots, wash fixtures, LEDs, etc.
- **Draw the stage and set in 2D** — Using the CAD tools such as lines, polylines, arcs, circles, and regions, a 2D plan view can be drawn on top of the drawing of the venue.
- **Create a 3D model using extrude tools** — Once you have a 2D plan view of the stage and set, use the extrude tool to create 3D objects from a region; for example, extrude a rectangle to create a single step or a riser. From an elevation view you can extrude a right triangle to create a ramp.
- **Add rigging and lighting** — Using the library of predefined blocks, add truss, pipes, lighting, projection, and other design elements. A block is a drawing that can be inserted into another drawing. It usually has attribute data including photometrics such as luminous intensity, physical data such as weight, and control information such as DMX512 slot footprint.
- **Add labels and attributes** — Once the lighting plot is laid out, each fixture should be numbered and the circuit, channel, dimmer (if applicable), DMX512 address, and other attributes can be assigned.
- **Create a layout** — When the design is finished, it can be plotted using different views including a plan view (looking straight down from above), elevation view (looking at the structure from the

side, which reveals height and other vertical dimensions), or an isometric view (looking at it from an angle).

With this job done, the light designer can import the drawing to the visualization stage where light show pre-programming is carried out and rendered. When finished, the preview can be sent to the show director or club owner for approval.

Appendix B

VRLight's Fixtures

VRLight exposes 5 different types of fixtures, which represent the most common choices in show business nowadays. Figure B.1 contains a table with the equipments' descriptions: type, controllable channels and common usage in event lighting. A scalable approach was taken to ensure easy addition of new fixture models. To add new equipment, the respective 3D model, texture, behavior script and Unity3D's prefab file shall be added to the resources folder and the new unit is ready to use.

PAR 56 LED Projector	
Type: PAR can - parabolic aluminized reflector led can	
Channels: red, green, blue, dimmer, strobe	
Common usage: theatrical or live music shows	
Martin Atomic 3000	
Type: white strobe light - flashtube	
Channels: strobing speed	
Common usage: live music shows, nightclubs, raves	
Super Laser 200	
Type: RGB laser projector	
Channels: red, green, blue, dimmer, macros	
Common usage: live music shows, nightclubs, raves	
Gobo Projector LED	
Type: LED gobo projector	
Channels: red, green, blue, dimmer, gobo macros	
Common usage: theatrical, live music shows, nightclubs	
MAC 250	
Type: PAR can - parabolic aluminized reflector led can	
Channels: red, green, blue, pan, tilt, dimmer, strobe, macros	
Common usage: live music shows, nightclubs	

Figure B.1: VRLight's fixtures.

Appendix C

User tests

C.1 Task times

The following tables represent the detailed elapsed times per user for each of the three proposed tasks:

- Task 1 - User movement
- Task 2 - Adding light fixtures to an empty structure
- Task 3 - Aiming lights to the band members

User Name	Task 1 (mm:ss)	Task 2 (mm:ss)	Task 3 (mm:ss)	Task 3 Method
Pedro Pascoal	02:57	02:58	01:08	JM
Pedro Santos	02:15	02:03	02:05	JM
João Guerreiro	01:43	01:51	02:29	PG
João Sousa	02:05	02:10	02:49	PG
Diana Gomes	01:07	01:54	01:19	PG
Catarina Machado	01:45	02:08	02:01	PG
Eugennio Di Tullio	01:29	01:41	02:11	PG
Patrícia Oliveira	03:45	02:58	03:20	PG
Cristina Antunes	03:10	02:10	02:33	PG
Marta Dornellas	02:22	01:58	02:03	PG
Rita Lindley	02:30	01:56	02:15	PG
Victor Torres	02:06	02:56	02:45	PG
Diogo Gil Henriques	01:57	02:23	01:18	PG + JM
Tomás Araújo	01:18	02:10	01:46	PG + JM
Eduardo Araújo	01:31	02:09	02:50	PG + JM
Tiago Ribeiro	01:39	01:33	02:28	PG + JM
João Pedro Lima	02:38	02:21	01:49	PG + JM
Vasco Correia	02:00	01:43	02:09	PG + JM
Madalena Araújo	01:57	01:59	02:32	PG + JM
João Marco	01:55	02:00	03:18	PG + JM

Task 1	
Minimum time	01:42
Maximum time	03:45
Average	02:06

Task 2	
Minimum time	01:33
Maximum time	02:58
Average	02:09

Task 3	
Minimum time	01:08
Maximum time	03:20
Average	02:15

Task 1	JM	PG	PG+JM
Q1	0,101	0,0719	0,0674
Q3	0,1156	0,1028	0,0818
Average	02:36	02:12	01:51
Av - Q1	00:10	00:28	00:14
Q3 - Av	00:10	00:16	00:06

Task 1 using Joystick mode	
Minimum time	02:15
Maximum time	02:57
Average	02:36

Task 1 using Point and go	
Minimum time	01:07
Maximum time	03:45
Average	02:12

Task 1 using PG + JM	
Minimum time	01:18
Maximum time	02:38
Average	01:51

ALL	Task 1	Task 2	Task 3
Q1	01:42	01:55	01:58
Q3	02:24	02:12	02:36
Average	02:06	02:09	02:15
Av - Q1	00:24	00:13	00:17
Q3 - Av	00:17	00:03	00:20

Figure C.1: Task times detailed study.

C.2 Questionnaire

Figure C.2: Questionnaire part one.

VRLight - Testes com Utilizadores

Este questionário pretende recolher o feedback do utilizador para a aplicação VRLight, após realizadas as três tarefas pedidas. Desde já agradecemos a sua participação!

Utilizador

1. **1. Nome**
(opcional)

....

2. **2. Idade** *
Mark only one oval.
- ◯ menos de 18
- ◯ 18 a 23
- ◯ 24 a 30
- ◯ 31 a 40
- ◯ 41 a 50
- ◯ mais de 50

3. **3. Género** *
Mark only one oval.
- ◯ Masculino
- ◯ Feminino

Experiência anterior

4. **4. Já tinha utilizado algum destes dispositivos?**
(antes do teste que acabou de realizar)
Check all that apply.
- ☐ Óculos de realidade virtual
- ☐ SpacePoint Fusion / Wiimote / PS Move ou semelhante

5. **4.1 Se escolheu alguma das opções anteriores - Em que situação utilizou o/os dispositivos?**

....

....

6. **5. Já utilizou um Joystick?** *
Ex. jogos/simuladores de aviões
Mark only one oval.
- ◯ Sim
- ◯ Não

7. **6. Já utilizou o protocolo DMX?** *
Mark only one oval.
- ◯ Sim
- ◯ Não

Figure C.3: Questionnaire part two.

8. **6.1 Se respondeu "Sim" à questão anterior - Em que situação utilizou DMX?**

9. **7. Se já utilizou algum software para pré-visualização da iluminação, por favor indique qual/quais**
(ex. ESP Vision, WYSIWYG, ShowDesigner)

10. **8. Classifique o grau de sucesso com que utilizou o modo "Change Position"** *
(apontar para o destino e escolher orientação)
Mark only one oval per row.

1 - Muito difícil	2 - Difícil	3 - Médio	4 - Fácil	5 - Muito Fácil
◯	◯	◯	◯	◯

11. **8.1 Se respondeu à questão anterior com 3 ou menos, por favor indique as razões que dificultaram a tarefa:**
Check all that apply.

- ☐ Sensibilidade elevada na colocação do cursor no local desejado
- ☐ Sensibilidade elevada na rotação do cursor para escolha da orientação
- ☐ Dificuldade em ver o cursor
- ☐ Náuseas causadas pelo movimento
- ☐ Other:

12. **9. Classifique o grau de sucesso com que utilizou o "Joystick Mode"** *
(inclinação/rotação do PNI SpacePoint Fusion)
Mark only one oval per row.

1 - Muito difícil	2 - Difícil	3 - Médio	4 - Fácil	5 - Muito Fácil
◯	◯	◯	◯	◯

13. **9.1 Se respondeu à questão anterior com 3 ou menos, por favor indique as razões que dificultaram a tarefa:**
Check all that apply.

- ☐ Sensibilidade elevada na deslocação
- ☐ Sensibilidade elevada na rotação
- ☐ Náuseas causadas pelo movimento
- ☐ Other:

14. **10. No geral, qual dos modos achou mais adequado para a deslocação?** *
Mark only one oval.

- ◯ Modo Change Position - Apontar para destino e escolher orientação
- ◯ Modo Joystick
- ◯ Ambos fornecem modos de deslocação úteis para a interacção

15. **11. Considera relevante poder mudar a altura do utilizador?** *
(View Height no menu de deslocamento)
Mark only one oval per row.

1 - Nada relevante	2 - Pouco relevante	3 - Relevante	4 - Muito relevante
◯	◯	◯	◯

Figure C.4: Questionnaire part three.

☐ Other: ....

14. **10. No geral, qual dos modos achou mais adequado para a deslocação?** *

Mark only one oval.

- Modo Change Position - Apontar para destino e escolher orientação
- Modo Joystick
- Ambos fornecem modos de deslocação úteis para a interacção

15. **11. Considera relevante poder mudar a altura do utilizador?** *

(View Height no menu de deslocamento)

Mark only one oval per row.

1 - Nada relevante	2 - Pouco relevante	3 - Relevante	4 - Muito relevante
◯	◯	◯	◯

16. **12. Considera relevantes as posições pre-definidas?** *

(Go To no menu de deslocamento)

Mark only one oval per row.

1 - Nada relevante	2 - Pouco relevante	3 - Relevante	4 - Muito relevante
◯	◯	◯	◯

17. **13. Se sentiu falta de alguma posição pré-definida, por favor indique qual/quais:**

....
....
....
....
....

18. **14. Se quiser deixar mais algum comentário ou sugestão relativos aos modos de deslocamento:**

....
....

Edição de Luzes

19. **15. Classifique o grau de dificuldade que sentiu ao tentar aceder a um Menu de edição de luzes** *

Mark only one oval per row.

1 - Muito difícil	2 - Difícil	3 - Médio	4 - Fácil	5 - Muito Fácil
◯	◯	◯	◯	◯

20. **16. Classifique o grau de dificuldade que sentiu ao tentar acertar nos botões do Menu de edição de luzes** *

Mark only one oval per row.

1 - Muito difícil	2 - Difícil	3 - Médio	4 - Fácil	5 - Muito Fácil
◯	◯	◯	◯	◯

21. **17. Classifique o grau de dificuldade que sentiu ao tentar apontar uma luminária** *

(através do método Aim Light)

Mark only one oval per row.

1 - Muito difícil	2 - Difícil	3 - Médio	4 - Fácil	5 - Muito Fácil
◯	◯	◯	◯	◯

Figure C.5: Questionnaire part four.

22. **17.1 Se respondeu à questão anterior com 3 ou menos, por favor indique as razões que dificultaram a tarefa:**
Check all that apply.

- [ ] Sensibilidade elevada na colocação da mira
- [ ] Dificuldade em ver a mira
- [ ] Má escolha de posição de onde apontei a luminária (muito longe, muito perto, etc)
- [ ] Other:

Comentários / Sugestões Finais

23. **18. Se quiser deixar mais algum comentário ou sugestão para a aplicação VRLight:**

C.3 Questionnaire results

	Movement ease of use		Best method	View height and predef.		Light editing menu and aim ease of use		
User Name	PG	JM	BEST	VH	PREDEF	MENUAC	MENUBTN	AIM
Diogo Gil Henriques	5	2	PG + JM	4	4	5	5	4
Tomás Araújo	5	5	PG	3	4	5	5	4
João Guerreiro	4	2	PG + JM	4	4	5	5	5
João Sousa	4	4	PG	3	4	5	4	2
Eduardo Araújo	4	4	PG	3	4	5	5	4
Diana Gomes	5	3	PG + JM	4	3	5	5	3
Pedro Pascoal	5	3	JM	4	4	5	5	5
Catarina Machado	5	2	PG + JM	4	4	5	4	3
Eugennio Di Tullio	4	3	PG	3	4	5	5	4
Patrícia Oliveira	4	2	PG	4	4	5	5	2
Tiago Ribeiro	3	2	PG + JM	4	4	5	5	5
João Pedro Lima	3	2	PG + JM	3	4	4	4	2
Pedro Santos	4	4	JM	4	4	5	4	4
Vasco Correia	4	3	PG + JM	4	3	5	5	4
Madalena Araújo	4	3	PG + JM	4	4	4	4	4
Cristina Antunes	5	1	PG	4	4	5	5	2
Marta Dornellas	5	2	PG	3	4	5	5	3
João Marco	4	3	PG + JM	3	4	5	5	2
Rita Lindley	4	3	PG	4	3	5	5	2
Victor Torres	4	2	PG	4	4	5	5	5

Figure C.6: Questionnaire results for user evaluation in movement features and light editing menu ease of use.