CAPSTONE RESEARCH REPORT

Matching Physical Lighting with Virtual Lighting for Virtual Productions: A Case Study at Breda University of Applied Sciences' Extended Reality Stage

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Abstract

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Matching Physical Lighting with Virtual Lighting for Virtual Productions: A Case Study at Breda University of Applied Sciences' Extended Reality Stage

By Shanna Koopmans

This study investigated how physical lighting can be best matched with virtual lighting for virtual productions at the XR stage at Breda University of Applied Sciences. This has been done by gathering different techniques from exploratory interviews with industry experts and testing those techniques at the XR Stage at BUas with a self-created virtual production set-up. The research report includes a comparative analysis of these techniques, with the conclusion that there currently is not enough knowledge yet to implement a proper technique that would improve the process of lighting design for students. So, the recommendations include more extensive research and possibly the development of an application to make the process of matching physical and virtual lighting easier. Consequently, the researcher has created a separate document containing practical suggestions that were mentioned by the interviewed industry experts with the aim to make the process of lighting design easier for students using the XR Stage at BUas. To discover whether this document was the desired level of clarity and useful, the researcher conducted a round of testing where a small number of participants created a lighting design using the document. A survey

afterwards concluded that in general the document was deemed useful to the participants and with minor adaptations the document could be implemented for use at the XR Stage at BUas.

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List of Abbreviations

3D **Three dimensional:** An image or object with three dimensions: depth, width and height.

BUas **Breda University of Applied Sciences:** Higher education institute in the Netherlands.

LED **Light Emitting Diode:** A device which emits light when an electric current passes through it.

XR **Extended Reality:** An umbrella term for multiple immersive technologies that mix virtual worlds and physical worlds such as: Virtual Reality, Mixed Reality and Augmented Reality.

1. Introduction

1.1 Focus of the Study

This research report presents and compares multiple existing techniques for aligning virtual and real-world lighting. The existing techniques have been examined under identical conditions to determine the optimal approach and clarify the underlying factors contributing to its efficacy. Virtual production is a film production process that involves using the LED wall which displays real-time photos, videos, or 3D environments. The 3D environments are created in Unreal Engine, a game development engine created by Epic Games ("Unreal Engine", n.d.). This technique allows actors to be more immersed in the setting and for filmmakers to immediately make changes to the environment instead of having to wait until post-production (Santos, 2023). The technology was first used in a high-profile way during the filming of The Mandalorian in 2018 (Purtill, 2023).

1.2 Client

Breda University of Applied Sciences, BUas, owns an Extended Reality, XR, stage including an LED screen and ceiling ("What is an XR Stage?", 2022). The XR stage is mainly used for educational and research purposes by staff and students, including Cradle. Cradle is a research and development lab within the games and media academy, part of BUas ("Media Research", n.d.). As previously stated, a game engine such as Unreal Engine is essential for virtual production in order to create 3D environments to be displayed on LED walls on set in real-time (L'Italien, 2022). For traditional filmmaking, the actors and set need to be lit, however with virtual production the 3D environments are also lit. Therefore, this study determines the optimal approach to match the physical lights and the virtual lights.

1.3 Industry Challenge and Research Problem

There is extensive knowledge on how to light actors in traditional filmmaking (Malkiewicz, 2012; Morehart, 2021; Stojšić, 2015). Additionally, there has been previous research done on lighting different moods in realistic scenes in Unreal Engine (Shelton, 2023) and lighting design in Unreal Engine for Virtual Reality (Martin, 2018). However, there is a lack of research on ways to match physical lighting with virtual lighting. Virtual lighting is a form of illumination that uses real-time engines to create light ("What is Virtual lighting in virtual production?", n.d.). Physical fixtures are used to augment the LED light and ensure that the talent, cast and physical props integrate with the colors of the virtual environment in frame (Herr, 2022). The physical and virtual lighting must match for the scene to look believable and realistic on camera. Currently the lighting design for a virtual production shoot at BUas takes a lot of time and is usually a trial-and-error process during both pre-production—and the production phase, this is caused by the fact that the technologies used in virtual production are still relatively new; the Mandolarian which came out in 2019 was one of the first to use an LED screen on their set ("The LED Screen Revolution", 2020) and BUas has started using their LED screen in 2022 ("What is an XR Stage?", 2022). This limitation currently results in a substantial amount of time being lost, occasionally having to settle for physical and virtual lighting not fully matching, or not having the ideal lighting design.

1.4 Industry- and Academic Relevance

This report provides detailed descriptions of several established methods for aligning physical and virtual lighting, offering a convenient resource for industry professionals, educators, or enthusiasts keen on virtual production to explore various approaches in one location. Moreover, individuals within the virtual production field, equipped with the same technology as BUas could also implement various practices described in detail in this paper for matching the physical and virtual lighting. The result of this report and the separate document created based on it allows future students and Cradle interns to gain a better understanding on how to match the physical lighting and the virtual lighting in their virtual production, which could save them time and have a more realistic lighted end result.

1.5 Research Objective

To summarize; this study aims to determine how physical lighting can be best matched with virtual lighting for virtual productions at the XR stage at Breda University of Applied Sciences. By researching different, existing techniques to match physical lighting on set and the lighting in Unreal Engine (Unreal Engine, n.d.) and attempting to implement said techniques during a self-created virtual production set-up, the research report describes and assesses each technique. Throughout the process of researching, the report also includes what the essential, required steps are to illuminate an existing environment in Unreal Engine (Unreal Engine, n.d.) effectively and how proper lighting can be achieved in a nighttime scene within Unreal Engine (Unreal Engine, n.d.) without inducing moiré artifacts.

2. Literature Review

2.1 Lighting in Film Production

The history of cinema lighting can be traced back to the early 1900s, when film production lighting was still primitive and mainly used for illumination (Swarnakar, 2023). Swarnakar (2023) continues to explain that the history of cinema lighting exists out of overlapping forces that includes technological and artistic advances and the inventive use of gained knowledge over time. Around the 1920s there were already hundreds of conventions, a recommendation of what to do in a certain cinematic context, that most studio cinematographers knew as they offered a basic starting point for arranging the lighting of any given scene (Keating, 2010). Some of the conventions were suggestions, however others were considered mandatory, for example, always using enough light to get exposure (Keating, 2010). Lighting in film is about more than making things visible; it allows to adjust and manipulate the impression conveyed on the screen (Millerson, 2013). Scene lighting is usually built, meaning that it happens one light at a time since it is quite complex (Brown, 2018). In a research study, Matbouly (2022) found that there are direct relationships between different colors of cinematic lighting, the perceived mood and appearance of film characters, and the audience's perception of the mood and appearance of film characters. Certain lighting techniques in film have connotative meanings: lighting from above is linked to spirituality, lighting from below is generally unfavorable, lighting from a 45-degree angle is generally favorable, lighting from the front is perceived as blandness and lighting from the back is usually perceived as mysterious (Kraft, 1991). In the book 'Shaping Light for Video in the Age of LEDs', Steinheimer (2020) describes how nowadays a lot more different light sources are being used and mixed in production compared to the past, which means that there is a bigger variety of choices and techniques.

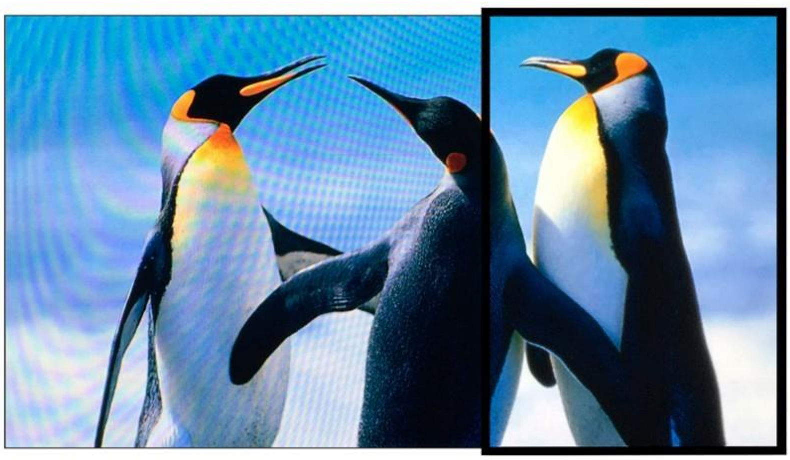
2.2 Lighting in Game Engines

Game engines are the software skeletons on which games are built with its purpose ranging from providing basic functions that will save a developer time, to having a full variety of tools and systems that can be used to speed up the game development process (Bullock, 2023). Not only are game engines utilized for creating games, additionally they are also applied in a variety of fields. For instance, game engines are used in healthcare and the military to create virtual simulations for training purposes (Lozé, 2020). Additionally, game engines have changed, and continue to change the film industry drastically; rendering visuals in real-time are used in the production process so the actors and director immediately can see the scene and effect which increases the realism of the actors their reaction, the option to add hyper-realistic 3D models and in recent iterations of gaming engines the geometry of objects and lighting are hyper-realistic ("Using Game Engines For Cinematography and Film Production", 2024). Thief's Dark Engine, a 3D game engine used between the years 1998 and 2000, was one of the first game engines to use light as an artificial intelligence, AI, aware gameplay element ("Leveling up by light: a look at lighting in video games", 2020). Another development followed not long afterwards in 2002, when a video game called Splinter Cell (Ubisoft, n.d.) was one of the first using a modified Unreal Engine 2 where AI is aware of the lighting ("Leveling up by light: a look at lighting in video games", 2020). Nowadays there is a wide variety of options available in game engines to create lighting. Radivojevic (2024) described that there are five different types of lights in games; directional lights, point lights, ambient lights, area lights and spotlights. They continued explaining that directional lights simulate sunlight, illuminate the entire scene uniformly and cast shadows; point lights represent a single light source emitting in all directions; ambient lights provide overall illumination without a specific direction; area lights represent a light source with an area, like a rectangular panel and spotlights, which emit light in a specific direction and create focused beams. To calculate lighting, game engines use real-time rendering techniques such as ray tracing and rasterization. Thomas (2019) explained that ray tracing is a rendering technique where an algorithm traces a path of light and then simulates the way the light interacts with the virtual objects it hits in the computer-generated world. With rasterization, the 3D software figures out the color of each pixel of the 3D object depending on the positioned light source (Winchester, 2019). Winchester (2019) continued describing that often extra lights are required in a scene to truly achieve the lighting effects that are needed, since light does not bounce in a rasterizer as it does in real life. To create the lighting in 3D environments, three of the most utilized techniques include static lighting, dynamic lighting and global illumination ("Illuminating Game Worlds: The Art of Game Lighting", n.d.). This article continues to describe the three techniques as follows: Static lighting is mostly used for non-moving light sources such as a lamp or sunlight as it is pre-calculated and does not change in real-time. Dynamic lighting on the other hand involves lights that can move and change in real-time such as flickering candles and moving shadows, the changes being in intensity, color and direction ("Illuminating Game Worlds: The Art of Game Lighting"), n.d.). Global illumination simulates how light bounces and reflects off surfaces, which results in a more realistic and natural-looking environment ("Illuminating Game Worlds: The Art of Game Lighting", n.d.).

2.3 Moiré Effect in Film

Figure 1 (Taylor, 2022) shows an example of moiré, which is described as an optical phenomenon that occurs when a pattern on your subject meshes with the pattern on the imaging chip of the camera, which creates an unwanted third separate pattern ("What Causes Moiré, How To Avoid It & How To Remove It", n.d.).

Figure 1



By M, Taylor, 2022, online sourced image from CTSAVL. https://www.ctsavl.com/the-moire-effect/

Moiré often appears on LED screens, however on a LED television it often does not appear since the pixels are right next to each other (Taylor, 2022). This article continues to state that LED walls have gaps between the pixels, therefore moiré occurs more often. Kupshukov (2023) gives multiple possibilities to reduce moiré, such as anti-aliasing filters, adjusting capture parameters and solutions to reduce moiré during post-production such as using blur or smoothing tools in editing programs, frequency separation and texture or pattern overlay.

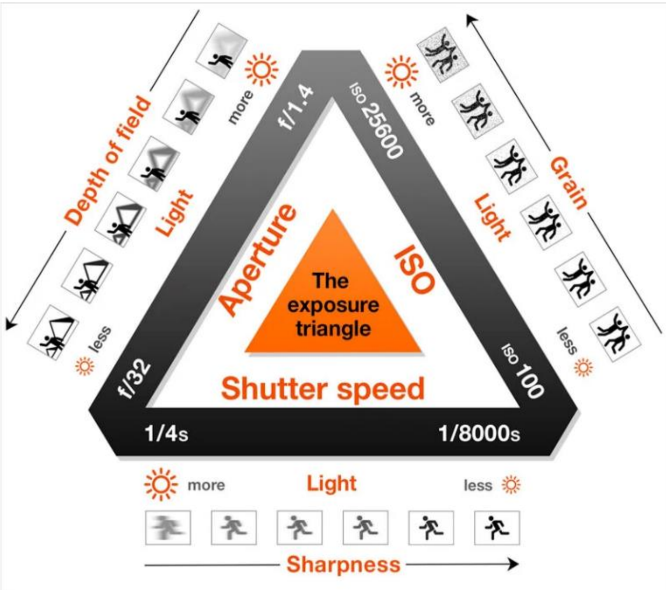
In virtual production, where crew work with a large LED wall, moiré is a recurring phenomenon caused by a multitude of reasons; Allowing the camera to focus on the LED wall panels, low LED refresh rates, sensor-LED pixel mismatch, reflections of light sources and lens and camera settings ("Moire effect on LED Screen: Causes, Prevention, and Solution). Currently, there are a variety of solutions known in the industry to prevent moiré including adjusting camera settings such as focal length, shutter speed and the angle, increasing the distance between the camera and LED wall, having foreground and middle ground set elements and having a proper lighting set up ("8 ways to remove the moiré effect of the LED display", 2023). This research includes testing with a nighttime exterior scene, having one fixed camera point and experimenting with physical set lighting, which as discussed prior, are conditions that are prone to cause moiré effect.

2.4 Camera Settings

This chapter dives into the different settings of a camera that all somehow influence the lighting of a video or picture and could possibly have an effect on the outcome of this study.

Cameras possess multiple settings that a person can change to influence how a picture or video turns out. Coker (n.d.) considers light to be the main ingredient a camera uses to capture a picture and that many photos are often ruined due to the wrong combination of camera settings. Daniel (2021) formulated that the exposure triangle, shown in Figure 2, was first introduced, and popularized by Bryan Peterson in the early 1970s. The article continues to describe that Peterson identified shutter speed, aperture, and ISO, as the three key camera settings that determine the exposure and how they presented the concept of the exposure triangle.

Figure 2 *The Exposure Triangle is the visual representation of the relationship between three main components of Exposure: ISO, Shutter Speed, and Aperture.*

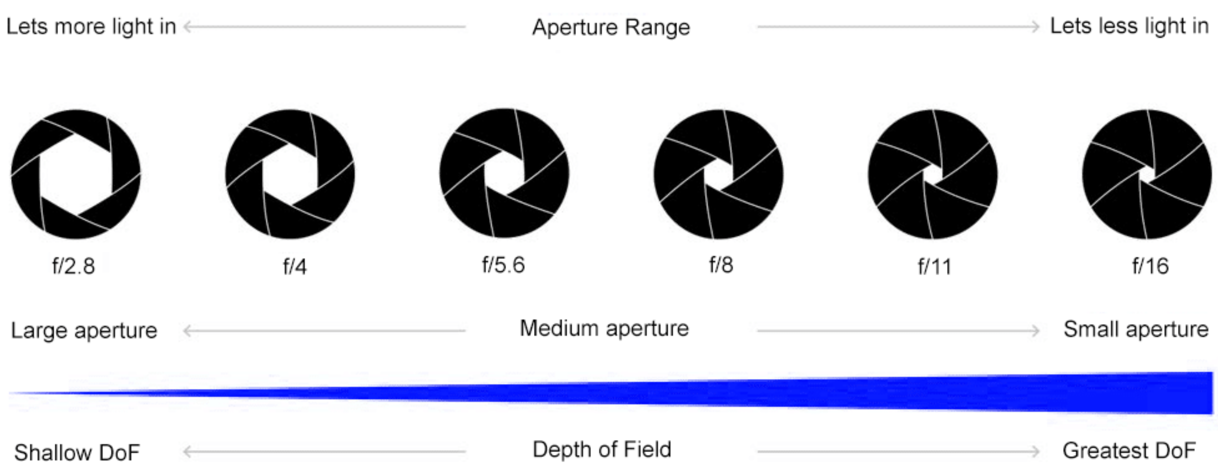


Note. By V. Elizarov, 2022, online sourced image from PetaPixel. https://petapixel.com/exposure-triangle/

2.4.1 Aperture

Artaius (2021) explains that the word aperture originates from the Latin term apertura, which translates to an opening. Essentially, aperture is the opening in the lens of a camera through which light passes (Artaius, 2021). Changing the aperture size consequentially alters the amount of light that reaches the camera sensor and therefore the brightness of the image or video (Mansurov, 2023). Mansurov (2023) describes how aperture also has an effect on the depth of field, which is defined as the amount of your photograph that appears sharp from front to back. Often in photography and cinematography, aperture is referred to as f-stop, which is usually indicated by the letter 'f' and then a number, such as f/5.6 (Deguzman, 2024). It was also noted by Deguzman that the smaller the number of the f-stop, the larger the aperture is and vice versa as can be seen in Figure 3.

Figure 3 *Aperture and F stop Chart.*



Note. By M. Stepanoff, 2020, online sourced image from Marat Stepanoff Photography. https://maratstepanoff.com/aperture-in-photography/

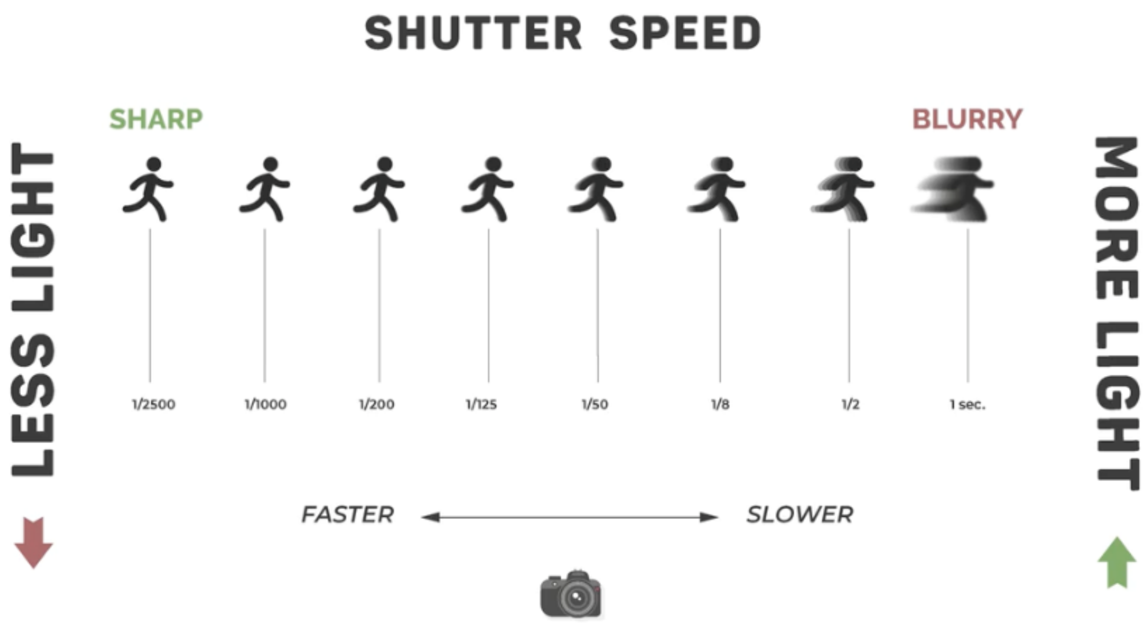
2.4.2 Shutter Speed

Hein (2022) defines shutter speed as the time in seconds that the sensor or film inside a camera is exposed to light to capture a photograph.

The shutter is a curtain in front of the camera sensor that remains closed until you start shooting. Once the button on a camera is clicked to capture an image, the shutter opens and lets in light that passes through the lens, exposing the sensor to it. Then the shutter closes again. The length of time the shutter remains open is determined by its speed (Davidson et al., n.d.).

If the speed is slow, the image or video will most likely be quite bright and if there are moving subjects present, it will cause motion blur (Maio, 2020). Sparks (2023) describes motion blur as an effect that photographers choose on purpose to use to smear or blur a moving object. Figure 4 shows how shutter speeds are measured in fractions of a second and displayed in numbers, so if the shutter speed is set to 25, the camera's shutter will be open for 1/25th of a second (Palad, n.d.).

Figure 4 *A shutter speed chart showing how different speeds affect light and motion.*



Note. By E. Greenawald, 2021, online sourced image from Skillshare Blog. https://www.skillshare.com/en/blog/a-beginners-guide-to-shutter-speed/

2.4.3 ISO

ISO controls how responsive the camera sensor is to light (Watterson, 2024). A low ISO number will result in a darker image; however, it ensures that the quality of the image or video will be smoother (Mireles, 2023). Watterson (2024) describes that increasing the ISO value not only makes the video or image brighter, at the same time it creates digital noise, which will show up as bright pixels or tiny spots on the image. ISO values often range between ISO 100 and ISO 6400, with each ISO value representing a doubling of the image sensor's light sensitivity ("Learn About Photography: What Is ISO?", 2021).

2.4.4 Camera Settings in XR

As mentioned earlier in this chapter, settings such as ISO, shutter speed and aperture affect lighting and the overall look of the scene, which still applies in virtual production. An additional term that is of importance when filming in an XR stage and using an LED wall is Depth of Field, which essentially refers to a portion of the scene that is sharp and in focus and is mostly adjusted by the aperture size (Santos, 2023). Depth of Field needs to be managed carefully; if the camera focusses fully on the LED wall moire and other aliasing issues will appear and if the depth of field is too shallow the depth rendered in the environment will not be seeable anymore ("Virtual Production FAQ", 2022).

Whereas traditional filmmaking uses one or multiple physical cameras, virtual production additionally makes use of Cine Camera Actors in Unreal Engine (Epic Games, n.d.), which are cameras in the environment with additional settings that have the same behavior as real-world cameras. The Cine Camera Actor has a picture-in-picture window, which will show a preview of the camera view in the game engine so camera placement, framing and movements can already be experimented with before even setting up the physical camera. The Cine Camera Actor has properties such as lenses, focal length and f-stop to emulate the physical camera ("Cine Camera Actor, n.d.).

Camera tracking, which analyses the camera that films the live footage and creates an accurate virtual camera in the game engine environment, is often used in virtual production. During this process software analyses the movement of the camera by identifying markers or points in the footage, which then get tracked to calculate the movement of the camera and position in 3D space and consequentially the software creates the virtual camera to match those positions and movements of the physical camera in the shot (Santos et al., 2023).

2.5 Postprocessing of Unreal Engine and Camera

Post-processing effects in Unreal Engine (Unreal Engine, n.d.) give designers and artists the possibility to define the overall feel and look of a scene through a combined selection of properties and features that affect lighting, coloring, tone mapping and more before it is rendered. To access these features in Unreal Engine (Unreal Engine, n.d.), a Post Process Volume can be added to a Level. A Level is all or part of the world the user creates and contains environments, characters, and objects ("Levels", n.d.).

It is a possibility to either add multiple volumes to define the look of a specific area or it can be set to affect the entire scene. Using a Post Process Volume has multiple advantages including real-time adjustability, the option to layer and blend different effects seamlessly, centralized control for artists and designers to easily tweak the overall feel of a scene, consistent color across different display types and separation of post-processing from other game systems to make managing and maintaining the visual effects individually easier ("Post Process Effects", n.d.).

Because Post Process Volumes can affect only part of a scene, different parts of the scene can be treated differently and have a variety of lighting conditions (Santos, 2023). All these advantages result in a more streamlined and efficient workflow ("Post Process Effects", n.d.).

A Post Process Volume in Unreal Engine (Unreal Engine, n.d.) has a variety of properties and settings:

Similar to real-world cameras, Depth of Field applies a blur to a scene based on the distance in front or behind a focal point. Bloom is a lighting effect that adds to the realism of the rendered image by reproducing glow around reflective surfaces and lights. Exposure has a multitude of options to select the exposure method used and specification of how dark or bright it should allow the scene to become over a selected period of time. There is an effect called chromatic aberration, which simulates the color shifts in real-world camera lenses. Additionally important to the lighting are Lumen Global Illumination, which works with all lights and any emissive materials that cast light, and Reflections, which gives multiple options for types of dynamic reflections. The category Color Grading has sections containing color balance for shadows, highlights, global and midtones and color temperature control ("Post Process Effects", n.d.).

3. Methodology

RQ: How can Physical Lighting be best matched with Virtual Lighting for Virtual Productions at the XR Stage at Breda University of Applied Sciences?

In this chapter, the research design, method, instrument of data collection, procedures for data collection, material, procedures for data analysis and ethical considerations will be discussed. The research question is constructed to explore multiple existing techniques from industry experts to match physical and virtual lighting in a virtual production scene. Therefore, a comparative analysis will be performed to evaluate which technique would be most suitable for the XR stage at Breda University of Applied Sciences.

3.1 Research Design

Aspers and Corte (2019) defined qualitative research as an iterative process in which improved understanding to the scientific community is achieved by making new significant distinctions resulting from getting closer to the phenomenon studied. A qualitative approach has been chosen for this research as the study requires physical testing of existing techniques and would result in a research report with a document of best practices based on experience for future students. The techniques stem from exploratory interviews with industry experts who use these steps and techniques themselves during work. This research requires a structure that allows adaption throughout the processes. Therefore, a quasi-experiment suits this project. Once the document is created, a small group of students will test out the practices and fill in a survey afterwards so the researcher will have feedback regarding the clarity of the document and whether it is considered useful to students with no or limited prior knowledge.

3.2 Participants

The participants were chosen based on non-probability sampling and convenience sampling. Nikolopoulou (2022) explained non-probability sampling as a method that uses non-random criteria such as geographical proximity, availability or expert knowledge of the individuals to answer a research question. Convenience sampling is a non-probability sampling method where participants are selected because the researcher has the easiest access to them (Nikolopoulou, 2022). As the intended audience for the final research report and the best practices based on experience document are students and future interns at Cradle, the selected participants are students who currently use the XR Stage.

It is vital to have those students as participants to assure the clarity of the instructions in the separate document and to assess whether it is valuable and useful information for the intended audience.

The sole criteria to determine which students will be included is whether they have prior knowledge of techniques to match physical and virtual lighting. This criterion is applied to assure that the document will be beginner friendly and understandable.

3.3 Exploratory Interviews

Jain (2021) explained that exploratory interviews have been found to be useful in getting a larger understanding of why and how certain things happen. This study focused on using exploratory interviews to collect primary information needed for the experimentation and data collection phase. In exploratory interviews the questions are predetermined, the interviewees get to answer in their own way and the interviewer may ask more questions about interesting answers ("Research Methods for Information Research", n.d.). Additionally, exploratory interviews are valuable at the early stages to find out what concepts various people use ("Research Methods for Information Research", n.d.).

The interviews were all intended to be with industry experts to gather information on the techniques they use to match the physical lighting with the virtual lighting during their virtual productions. The researcher reached out and set up online meetings with three industry experts. The first interview took place on April 5th, 2024, with Jendrisak, who is a virtual production volume operator at Lukkien (Lukkien, n.d.). The second interview was with Boots, virtual production evangelist and de Bilde, creative director of Iron Films (Iron Films, n.d.) on April 19th.

A basic structure was premeditated, such as starting with an explanation of the research topic and the environment that is used during the testing phase, followed by a short list of lighting equipment that is available at the XR Stage at BUas. After the introduction, the researcher followed with a few questions that returned in each interview:

- What would your approach be to light a daytime exterior scene like that?
- Would that approach be any different for a nighttime exterior scene or would it be the same?
- Do you have any tips or tricks that you think are essential to know for students with limited prior knowledge and experience that want to do the lighting for their virtual production?

These questions were the foundation to receive the information needed to be able to conduct testing at the XR stage. Next to these questions, the researcher asked questions based on the answers given by the industry experts to dive deeper into interesting topics or comments made by the interviewees. The full interviews can be found in Appendix A.1. Additionally, signed consent forms by Jendrisak, Boots, and de Bilde are evident in Appendix A.1.2.

3.4 Instrument of Data Collection

To find a technique to match the physical lighting with the virtual lighting that will work at the XR stage at BUas, different existing techniques needed to be explored. This research chose to collect primary data, which Taherdoost (2021) defined as first-hand information which is specific to a problem and cannot be provided from published references. To gain primary data the researcher set up multiple interviews with industry experts, which is further explained in Section 3.3.

To discover whether the techniques provided by the industry experts were feasible with the equipment available at the XR stage, the researcher chose to conduct tests. Further elaboration about the testing is described in the following section of this chapter.

During the last phase of data collection, a survey was distributed to the students that tested the document created based on the outcome of the testing phase. Qualitative surveys are used to collect participants their experiences, opinions, and narratives (Ortega, n.d.). This method of data collection was chosen considering that the researcher wanted to gain opinions and suggestions on the document. The survey was made to be anonymous, as Balamurugan (2023) described that when a survey is anonymous, participants feel more inclined to provide honest feedback and opinions.

The survey contained nine questions; three questions with a slider to answer, three multiple choice questions with a text box option and three open questions with a text box. The multiple-choice questions with a text box included inquiry about their current experience with lighting at the XR stage, whether the best practices were explained well enough to utilize them during the creation of a lighting set up and whether the layout of the document contributed to having a clear overview and the ability to find specific information. These questions all had the options yes, somewhat and no and contained an additional text box to elaborate their answers. The survey questions containing a slider were to discover to what extent the practices were clear, to what extent the practices were new information for them and to what extent the document helped during the process of creating a lighting set-up. The open questions with text box were mainly focused on any suggestions or opinions that the participants had regarding improvement of the layout of the document and whether they believed the document could be useful for students during future virtual production projects. In the forming of the questions, the participants were encouraged to elaborate on their answer to gather more insights.

3.5 Procedures for Data Collection

During the experiment, each technique will be tested with one 3D environment and two scenes; a forest scene during daytime and a variation of the same forest scene during nighttime. Every taken step, every finding and any additional notes will be noted. The researcher made sure that during the second testing day the physical lights were not placed in the same spot as the previous day. It was important to not have the lights in the exact same spot, because otherwise it would make the amount of time it takes to set up significantly shorter during the second testing day.

To discover whether the best practices based on experience document is deemed useful and displays information clearly, students will test out the document by setting up lighting themselves and utilizing the document during the process. Afterwards, the students have been asked to fill in a survey.

The survey was distributed on May 13^{th}, 2024. Upon starting the survey, the first page contained information about the purpose of the survey and the participants their consent was asked, see Appendix A.2. All participants and their answers remained anonymous and were informed prior to starting the survey to hopefully ensure that all participants feel safe enough to give honest answers.

3.6 Materials

During the preparation of the data collection, Unreal Engine (Unreal Engine, n.d.) was used to retrieve and adjust an environment. During the data collection phase, the researcher made use of multiple pieces of equipment including: an ARRI Orbiter light (ARRI, n.d.) which can be seen in Figure 5, a Lupo light which can be seen in Figure 6 and a Bresser LED light which is shown in Figure 7, the LED screen and LED ceiling. Additionally, two white flags and a black flag were equipped as well as a Blackmagic URSA Mini Pro 12K camera and the software Vicon Shogun (Vicon, n.d.), which is being used at the XR stage to make use of camera tracking. Additionally, Helios is used, which provides in-camera visual effects specifically created with virtual production in mind (ROE Visual, 2024).

Important to note is that all the equipment used during the data collection is accessible at the XR stage at BUas.

Figure 5 *ARRI Orbiter Fresnel Lens 15-65° motorized open face optics.*

Note. Online sourced image from ultralite. https://www.ultralite.eu/products/arri-orbiter-fresnel-lens-15-65

Figure 6 *Lupo Movielight 300 Pro.*

Note. Online sourced image from CVP. https://cvp.com/product/lupo-900-movielight-300-pro-5600k

Figure 7 *BRESSER LED Photo-Video Set 3x LG-600 38W/5600LUX + 3x tripod.*

Note. Online sourced image from BRESSER. https://www.bresser.de/en/Photostudio/Continuous-Light/LED/BRESSER-LED-Photo-Video-Set-3x-LG-600-38W-5600LUX-3x-tripod.html

3.7 Procedures for Data Analysis

The initial gathered data was analysed using comparative analysis, which is defined as a method that compares two or more things to discover their similarities and differences (Dovetail Editorial Team, 2023). Using the comparative analysis method results in being able to identify strengths and weaknesses of all things compared and find the one that is most effective (Dovetail Editorial Team, 2023). Following the steps written by Walk (1998), the researcher started by establishing grounds for comparison before starting the initial testing phase. These steps took place and were documented before testing to ensure that any made arguments are meaningful and that the researcher can provide solid reasoning.

The researcher chose to compare only two techniques due to the length of the research period, which was five months. The choice of whom or which companies should be interviewed was based on the knowledge that both Lukkien and Iron Films often work with the technology utilized during virtual production shoots. Jendrisak is a BUas alumni who has used the XR stage before and the researcher found that they had a unique perspective, being able to speak from a combined point of view. Boots and de Bilde were selected for an interview since the researcher knew they had a similar interest and have been looking into solutions for lighting issues while using a LED wall as well.

After the initial testing, the techniques have been compared based on time, as the aim of using a certain technique is to make the process quicker. Something else that has been taken into consideration is how much and which equipment and software is necessary and additionally how much knowledge is required to be able to use the technique, as it is important that the technique should be doable even for students with no or limited prior knowledge.

During the second testing phase, where students test out the best practices based on experience document which has been written by the researcher, they will have filled in a survey afterwards. The data collected from the survey has been described in the results chapter of this report.

3.8 Ethical Considerations

To prevent the participants in the survey to have a lack of information, the first page of the survey contains information regarding the research report, the intention and how the given answers will be used. The students chose to participate voluntarily after the researcher gave an explanation about the project verbally, without any involvement of coercion, pressure or manipulation. None of the participants their names are involved in the answers or report as this is not relevant and to ensure that they can stay anonymous and feel free to answer in honesty. The survey contained a page asking for participants their consent before any questions appeared, see Appendix A.2, and the participants had the option to stop answering at any point during the survey.

4. Details of Experiment / Data and Results

In this chapter, the findings of the exploratory interviews will be explained, the details of the testing of two techniques will be given in detail along with the findings. Additionally, the details of the second experiment to explore the validity and clarity of an additional document created by the author will be explained.

4.1 Pre-Interviews Industry Experts

The different techniques described in this chapter are all techniques meant to match the physical lights on a set with the lighting in the environment. These techniques were explained by industry experts who all work for studios that conduct virtual production shoots professionally. To utilize the techniques, they are described thoroughly to ensure that even with limited prior knowledge it is comprehensible. The full interviews with Jendrisak, Boots and de Bilde can be found in Appendix A.1.

4.1.1 Lukkien Method

In the exploratory interview with Jendrisak, they described the approach Lukkien has when it comes to lighting a shoot, specifically a daytime exterior scene and a nighttime exterior scene.

The first step would be building the Unreal scene, having a render and having it up on the LED screen. This is followed by setting up the physical set and props and then the process of building the physical lights on set starts. At Lukkien they have multiple lights permanently hanging from the ceiling and the gaffer can add more lights if needed. Jendrisak explained that they use a skybox, which is a soft box from the ceiling with four to twelve ARRI sky panels (ARRI, n.d.) which is used as ambient lighting. Additionally multiple soft boxes are added from the front. When it comes to sunlight, Lukkien uses an ARRI light (ARRI, n.d.) from the side to match the sun in the environment and if the sun angle will change throughout the scene in the environment, they prebuild physical lights from multiple angles and turn on the one they need in that particular moment. The gaffer will tweak the intensity of the lights and color temperature to match the lights in the environment manually. At Lukkien they ensure that the gaffer knows the different shots and scenes in advance.

Jendrisak described that a nighttime scene still needs a lot of lights, and their setup would essentially be the same as the daylight, except for the main sunlight. The difference between the lighting setup of the two scenes is that their approach would be to change the aperture of the camera to make it darker.

Additionally, Jendrisak mentioned that they do not treat the LED ceiling and screen as a main lighting source. Instead, they use it as ambient lighting, whereas their physical lights are the main focus. They also mentioned that once the physical lights are set up, they put the camera in front of the scene and only tweak the lights based on how it looks through the camera or the monitor that shows the camera view to ensure that it looks realistic and well-lit in the captured footage.

4.1.2 Iron Films Method

In the exploratory interview with Boots and de Bilde, they described the approach Iron Films has when it comes to lighting a shoot, specifically a daytime exterior scene and a nighttime exterior scene.

For a shoot at Iron Films, they first get the image or environment up on the LED wall and put the camera in front of it. Instead of looking directly at the wall, they look at the monitor and make sure that the image that is seen through the camera is correct or whether changes need to be made to the image first. This is followed by putting the physical lights there and lighting the subject properly. Boots described that they would first set up a key light as the sun, which would be powerful enough to be believable as the sun. The sun key light would need to match the one in the environment which is usually at 6500K. Then they would start placing fill lights to soften any hard shadows and create toning. Boots and de Bilde additionally added that if there are artistic purposes when it comes to light, there are options to use different color temperatures to make a different color appear somewhere and mix and match multiple color temperatures in one scene.

Boots and de Bilde affirmed that the approach of lighting a nighttime scene would in essence be the same as the daytime one. If there is a full moon in the scene, at Iron Films they would use the same key light, however they change the color temperature to the color temperature of the moon. They describe that an LED wall is not good at having darker tones, so they essentially film it overexposed and turn it down in post-production.

Additionally, they mentioned that because the LED wall has a narrow color spectrum, they never use it to mainly light their subjects. A general approach they use at Iron Films is that they break the steps they take into pieces, meaning that they will ensure the environment on the screen looks good first, then the camera settings, then the physical lights. They also turn the lights off and on one by one to see what kind of effect the singular light has on the scene and if anything needs to be changed. At any given point, they look at the monitor instead of looking at the scene and wall directly, because the human eye reacts differently to light than the sensor of the camera.

4.2 Details Test Lukkien Technique

Following the routine and technique Jendrisak described the researcher first ensured that there was an environment to work with. On a planned day prior to the data collection in the XR stage, the researcher implemented the virtual production template, which was custom created by Cradle for the setup at BUas, in the environment, so it was usable on the LED wall.

The next step was to make any necessary changes to the environment, such as moving the virtual camera before building up the physical set, which included stage pieces, a tent and chair. The LED ceiling was turned on with part of the environment on it so the lighting of the wall and ceiling would be the same.

This was followed by setting up the physical lights, starting with setting up the Orbiter on the left side of the set. The researcher set the color temperature to 6000K, which is considered to be a color temperature of direct sunlight. To emulate the described technique, the Lupo was set up next to it with the same color temperature and on the other side a Bresser LED light was set up, which automatically has a color temperature of 5500K. Seeing as these are the only three main lights available at the XR stage, they were all utilized. The placement of the Bresser LED light was chosen based on where hard shadows were still visible in the shot when looking at the monitor. Once the lights were set-up and the amount of light looked decent, the researcher looked closely at whether the colors of the light looked realistic. Subtle tweaks were made in the intensity of the lights. When it comes to camera settings, the researcher used the following: ISO 800 and an aperture of two. In Figure 8 the final lighting setup can be seen for the daytime exterior scene.

Figure 8 *Lighting setup using Lukkien technique.*

Since Jendrisak described that the setup for a nighttime exterior scene would be the same, the researcher kept the setup and changed the color temperature of the Orbiter to 12000K, and the intensity was set at 20%. The lighting was still considered bright, especially for a nighttime scene, so following the approach used at Lukkien, the researcher changed the t-stop on the camera from two to four to make the scene appear darker.

4.2.1 Results

Following the technique provided by Jendrisak, it took the researcher around 45 minutes to have a lighting setup ready for the scene. It was not achievable to fully duplicate the approach Lukkien uses for virtual production shoots, since the XR stage does not have the same number of lights as Lukkien does. In Figure 9 the finalized shot of the daytime scene can be seen, and Figure 10 shows the final shot of the nighttime scene. There were no hard shadows evident in the shot and the sunlight emulated actual sunlight.

Figure 9 *Final shot daytime scene Lukkien method.*

Figure 10 *Final shot nighttime scene Lukkien method.*

Even with the darker tones on the LED wall, the camera had no issues with moiré showing up on the wall at any given point throughout the process.

4.3 Details Test Iron Films Technique

The researcher already had the environment ready since the same one was used for all tests. Following the technique and approach described by Boots and de Bilde, the first step was to get the environment on the wall.

The second step was to put the camera in front and as suggested by Boots and de Bilde, the researcher first checked if any changes needed to be made. This was not the case, so the researcher followed this by setting up the first light, which was the Orbiter. The Orbiter in this case was the key light that would function as the sun and it was set to 6500K, which Boots said was the color temperature they use at Iron Films for any lights that emulate the sun.

Because Boots and de Bilde described that they usually do things step by step and turn lights off and on to see the singular effect it has on the scene, the researcher followed this approach. After setting up the key light, the LED wall was put on blackout to check whether there was any light spill on the wall and to see what effect that singular light had on the physical set. The researcher noticed that the right side of the set was still very dark, so after getting the environment back on the screen, the Lupo light was placed on the right side of the set and set to the same color temperature of 6500K. Sticking with the approach, the Orbiter and the LED wall were put on blackout to see the effect of the Lupo light. The researcher noticed that the Lupo light did spill on the wall, so a c-stand was placed on the right of the light and a black flag was placed in the c-stand to block the light from spilling onto the wall.

When both lights and the wall were reactivated, the researcher noticed that there was enough light, however it was too bright and warm compared to the light in the environment. Therefore, a white flag was placed in front of the Lupo to soften the light. Boots and de Bilde had mentioned that for artistic purposes different color temperatures could be mixed in one scene, so because the researcher thought the lighting looked too warm, a LEDgo panel was added with a temperature of 5500K, which shone on the face of the character while sitting down.

Throughout the process of checking how all the different lights influenced the set individually, the researcher kept an eye on the monitor to verify what the camera recorded.

Since Boots and de Bilde mentioned that their approach for lighting a nighttime scene would be the same as for a daytime scene, the researcher left the lights in the same place. For the nighttime scene, the first step was to change the color temperature of the key light to emulate the color of light shining from a moon. The change was from 6500K to 7250K, and the intensity remained the same. The final lighting setup used for this scene can be seen in Figure 11.

Figure 11 *Lighting setup using Iron Films approach.*

4.3.1 Results

Following the technique described by Boots and de Bilde, the researcher had the lighting setup ready in around 65 minutes. Figure 12 shows the result of the daytime scene using the Iron Films technique and in Figure 13 the finalized shot of the nighttime scene can be seen.

Figure 12 *Final shot daytime scene Iron Films method.*

Figure 13 *Final shot nighttime scene Iron Films method.*

4.4 Details Test Best Practices Based on Experience Document

Multiple students were invited to the XR stage and showed up on May 13th, 2024. Two testing sessions took place, one in the morning and one in the afternoon. Testing in a duo and a group was selected over individual testing so the participants would vocalize their thoughts and suggestions during the process of setting up a lighting design and the researcher could observe their reasoning for the choices they made without interfering. Prior to the participants their arrival, the researcher set up the same environment that was used in the other rounds of testing, set up the camera and turned on the monitor. Additionally, the best practices based on experience document, which can be seen in Appendix A.3, was opened on a laptop to ensure the participants could read and get back to it at any given point in time. During the morning two students participated and in the afternoon four students participated. The researcher first informed both groups of the document, intended purpose and a brief description of the research that it was based on. This was followed by an explanation of what the participants were supposed to do: An environment was already present on the LED wall and the students had to create a lighting setup. Instead of having to light physical props, they had to light an actor standing in the middle of the space. Furthermore, an instruction given to the group of four was that they had to discuss their suggestions and that there could not be a leader of the group; individually they had to contribute an equal amount. The participants were not given any orders on which equipment they should utilize or in what order they should work. This approach was chosen to allow the participants to follow their instincts and impulses and to encourage open discussion. This was of importance to subtly assess whether the participants employed the practices originating from the document and any reactions to those. The researcher documented every step the participants took and findings by taking notes on their phone. Afterwards, when the students finished with their lighting setup, they were informed that a survey had been sent to them and they were kindly asked whether they could fill in the survey.

4.4.1 Details Duo Participants Experiment

After the briefing, the two participants started with reading the best practices based on experience document. Once they had read it, they grabbed two c-stands and the stands for the ARRI Orbiter light (ARRI, n.d.) and the Lupo light. They assembled both lights and one of the participants started experimenting with the camera settings such as ISO and white balance. In the meantime, the other participant started holding a white flag in front of the lights to see the effect of it. The student previously occupied with the camera now put up a black flag next to the Orbiter and went over to the computer to look for the color temperature of the lights in the environment. Unable to find the color temperature, the participants opted to look up the color temperature of sunlight online and adjusted the Orbiter and Lupo based on that. Following that, they turned the screen on blackout to check for light spill and adjusted the position of the black flags. They put up a Bresser LED light on the right side and put a black flag next it as well before they decided that they were finished.

4.4.2 Details Group Participants Experiment

The four participants in the afternoon also decided to start by reading the document before doing anything else. Before acquiring any equipment, the participants started discussing from which direction the sun came from in the environment. They set up the Orbiter and looked up the color temperature of the sun online. As the participants were attempting to find a designated spot for the light, they took a closer look at the shadows in the environment before one of the participants went over to the computer to have a wider view of the environment to find out where exactly the sun came from. The participants got the tube lights out and held one on each side of the actor to see what it added. At this point, they put the LED wall on blackout to check for light spill and chose not to use any black flags because the light spill was not significant enough on the monitor in their opinion. Subsequently, the color of the tube lights was changed to contain more of a green hue and the LED ceiling was utilized, also with a green hue to it. The participants did not seem to agree with each other about the placement of the lights, so half of them went outside to see what the sun and shadows do on objects and people. Based on that information, each light was moved closer to the actor, and they seemed satisfied with the result.

5. Discussion of Data and Results

In this chapter the findings of the experiments will be further discussed and what these findings might mean. The survey data will be explored in this chapter and arguments will be made based on the results.

5.1 Comparison of Techniques

As previously discussed in Chapter 3.7, the two tested techniques are compared on a few different criteria: time, needed knowledge, needed equipment and software. Comparing the techniques based on time, using the technique Jendrisak provided it took 45 minutes for the researcher to finish a lighting setup. Utilizing the technique from Boots and de Bilde, it took 65 minutes. The primary cause of the technique of Boots and de Bilde being more time-consuming was because their technique included checking what each individual physical light does to the set by turning the others off. Additionally, making modifications regarding color temperature, the intensity of the light and the direction. Whereas the technique provided by Jendrisak did not require assessing each light individually. Although it is preferable for the process of lighting and making it match to be less time-consuming, the approach of taking time to assess what each light contributes individually and making adequate changes before moving on could be more beneficial at the XR Stage at BUas. This approach could give students the opportunity to learn by making conscious decisions about what they want the light to do to the scene instead of randomly putting some lights together solely to ensure the subject is lit enough to ensure its visibility on camera.

For both techniques the same equipment and software were utilized such as Unreal Engine (Unreal Engine, n.d.), Vicon Shogun (Vicon, n.d), Helios (ROE Visual, 2024), the available physical lights, the LED wall and LED ceiling. Neither of the provided techniques specifically required any additional software to be installed equipped and there were no specific instructions on which physical lights were needed. However, Jendrisak did mention that Lukkien usually equips a multitude of lights that their studio permanently has hanging from the ceiling. This was not feasible to duplicate at the XR Stage at BUas, as the XR Stage does not have those means available. Consequentially, slight alterations needed to be made to perform the technique.

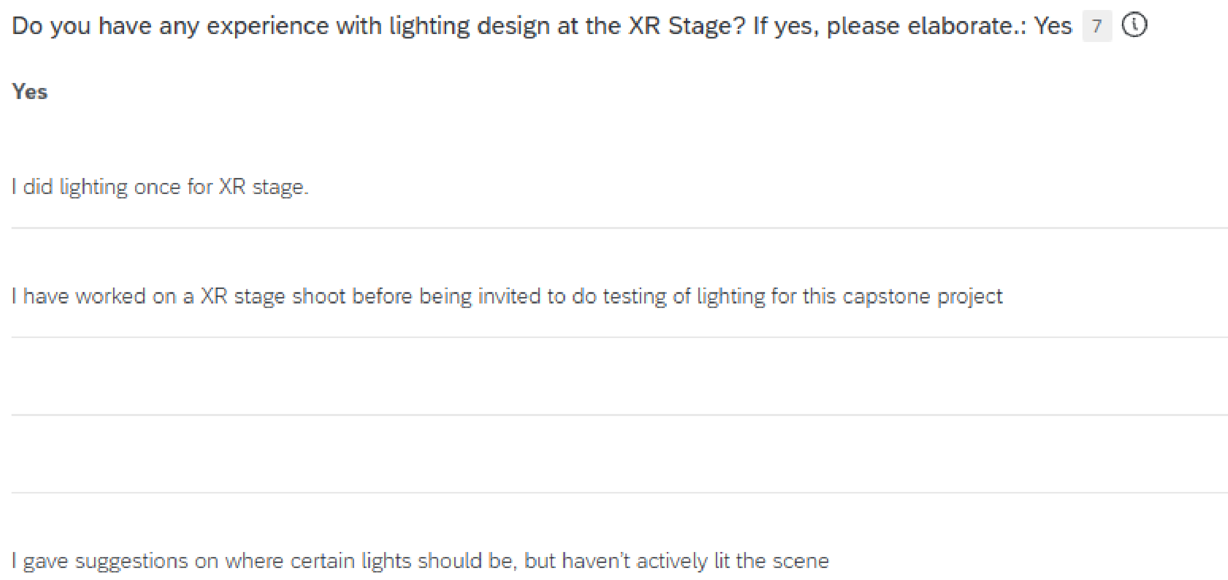
After the testing of both techniques, it became evident that a basic knowledge of how to set up the physical lights, light direction and lighting for film in general is essential. However, the XR Stage is mainly used for educational purposes and learning skills during virtual production projects is fundamental and prioritized since it is located at an educational institution. Therefore, most students working on virtual production will have the opportunity to gain a level of knowledge before having to properly work on creating a lighting design for a virtual production shoot and the fact that a basic level of knowledge is required to perform these techniques should not pose as a threat.

Something that stood out and became evident after the experiment was that both techniques from different studios were quite similar. In the big outlines, they both started with an Unreal Engine (Unreal Engine, n.d.) environment on the wall, followed by having a physical set built and setting up the physical lights. What is noticeable about both techniques is that no additional software or proven method was utilized to ensure that the physical and virtual lighting matched. The steps taken to attempt to match the physical and virtual lighting were mostly based on subjective viewpoints by an expert eye.

5.2 Survey Data

To assess the level of prior knowledge the participants had with lighting design at the XR Stage, a question was posed regarding their previous experience.

Figure 14 *Results question previous experience with lighting design*


Do you have any experience with lighting design at the XR Stage? If yes, please elaborate.: Yes 7

Yes

I did lighting once for XR stage.

I have worked on a XR stage shoot before being invited to do testing of lighting for this capstone project

I gave suggestions on where certain lights should be, but haven't actively lit the scene

Four participants answered that they had previous experience with lighting design at the XR Stage and two of them did not. The four participants who answered that they had previous experience all had a limited, yet different level of experience as seen in Figure 14. One other participant who answered 'no' elaborated that they only have experience with lighting game levels, whereas they do not have experience with physical sets.

Based on answers regarding the clarity of the document, referring solely to the way the information is written, the participants were mostly able to use the best practices from the document during the process of setting up lighting based on how the information was described. Four participants answered 'yes' and two answered 'somewhat' with additional comments including that some instructions were not applicable to their environment and that it helped dictate some of the steps taken to create a lighting setup. One participant stated the following: "The tips were informative and covered a decent amount of ground ranging from the virtual space all the way to the physical one. Improvements: Some of the language is complicated and needs prior knowledge to understand. Define what these words or phrases mean in the text, to the side, or as a footnote."

The current layout of the document exhibits its current visual characteristics due to deliberate choices. A question was inserted regarding the layout and whether it contributed to a clear overview of the practices and the ability to find specific information. Some of the given answers can be seen in Figure 15.

Figure 15 *Results question contribution of the layout to a clear overview*

Does the layout (the use of sections/color/bullet points/sentences in bold) of the document help with having a clear overview / finding certain information?

Yes

as someone who has problem of finding important information while scanning through text, this was an absolute life saver

I think visual can help and look pretty on the document

I will quickly associate a certain color with a certain part of the process immediately therefore looking for information later on is much more helpful and faster.

Furthermore, the survey provided the participants with the option to leave suggestions regarding the layout to further improve clarity and the ability to find specific information. Three major suggestions that were given stated: To provide the practices into a frequently asked questions format, inserting a table of contents and to insert more detailed explanations to the practices to increase the likelihood that an individual without prior knowledge of lighting would be able to understand the practices as well.

To discover whether the written practices were common knowledge and therefore not necessary, the participants were asked whether the practices were new information to them or not. On a scale from 0-100, the average answer was 51.67, which means that the participants on average knew about half of the practices already prior to reading the document and half of the described practices were new to them.

The question to what extent the document helped the participants during the process of creating a lighting set up contained a slider with a scale from 0-100 as well. The result was an average of 70.50, which means that the participants on average found the document to be helpful on a significant level.

Participants were given the opportunity to give any suggestions or comments about the document in general and one suggestion was mentioned more than once: Implementing visuals since some students are visual learners and that it could enhance the clarity of the described practice. Furthermore, one participant mentioned that they would like to see a general guide on how to do lighting design for XR. They suggested including how to navigate the most common issues that people run into when setting up physical lights for virtual production, different light sources in

Unreal Engine (Unreal Engine, n.d.) and recommended setups for certain conditions in an environment such as sunny weather, lighting for an interior environment or cloudy weather.

Lastly, based on their experience the participants were asked whether they considered the document to be useful for students during virtual production projects and why they did or did not consider that to be true. All respondents reacted positively, as can be seen in Figure 16.

Figure 16 *Results question regarding usefulness*

Do you think this document could be useful for students during their virtual production projects? Please elaborate 7

Do you think this document could be useful for students during their virtua...

Yes, especially for students new to xr and or lighting it could be very beneficial.

Absolutely, especially for the starting students with this technology. Making their productions easier and faster !

I think it's a good foundational guide for your basics, as ultimately every scene is different and requires a different approach. But when it comes to the XR stage at BUas, it is a good indication of the steps to take.

Yes the tips and tricks can be usefull for students.

I do think so, cause for new people it highlights issues that show up easily in XR with lighting that you don't think about

6. Conclusion and Future Directions

Based on the previously discussed data and results, this chapter will include conclusions and will simultaneously answer the predetermined research question and sub questions. Additionally, this chapter discusses the limitations that this study had and any future recommendations that the researcher has for the industry and for further research.

6.1 Conclusions

This research paper aimed to deduce how to best match the physical lights on set with the virtual lights in Unreal Engine (Unreal Engine, n.d.) for virtual productions at the XR Stage at Breda University of Applied Sciences. After a thorough literature review and interviews with industry experts, the findings showed that a certain technique, including software or any other technical innovation does not exist yet. However, numerous industry experts are currently researching and producing tools to make the process of matching the physical lights to the virtual ones easier and less time consuming, which is explained in further detail in Section 6.3. Even professional studios currently match their lighting based on what their gaffers think look best and the knowledge of color theory and color spectrums, see Appendix A.1. There is currently no straightforward solution, as virtual production is still relatively new. So, focusing on the research problem stemming from the client, Cradle, currently there is no one technique that can be implemented at the XR Stage at BUas. However, during interviews with industry experts, they revealed their practices for lighting a virtual production set and at the realization of how valuable these practices could be for students at BUas, the researcher decided to create a separate document containing these practices. The best practices based on experience document is not written or formatted academically, as the target audience is bachelor students, and the objective is for them to be able to comprehend and access the practices easily and quickly.

6.1.1 Sub Questions

To discover the answer to the question what the required essential steps are to effectively illuminate an existing environment in Unreal Engine (Unreal Engine, n.d.), the researcher started searching for video tutorials on YouTube. From a video uploaded by Faucher (2022), the researcher found insightful tips that are helpful especially for people with no or limited prior knowledge when it comes to illuminating an environment in Unreal Engine.

Most existing environments from the Unreal Marketplace (Unreal Engine, n.d.) contain pre-existing lighting. However, if someone would want to construct the lighting themselves or has created their own level and therefore needs to create the lighting as well, the information could be valuable.

The first required step would be to have an environment open on a desktop or laptop. If there is no pre-existing lighting setup in the scene, the first step would be to open the content drawer on the bottom left and search for Sky Sphere. After the Sky Sphere Blueprint is dragged into the environment, the sky should look like it does in Figure 15.

Figure 15 *Sky Sphere Blueprint in Content Drawer and in environment.*

After selecting the Sky Sphere in the Outliner on the right, the Details panel provides a slider for adjusting the Sun Height. This setting alters the color of the sky. For instance, setting the Sun Height to –1.0, turns the sky a dark blue color, resembling nighttime. If the desired lighting is nighttime, there is a Stars Brightness value in the Details Panel available to add stars.

The next step involves creating either a sun or a moon, depending on what the preferred time of day is for the environment or scene. One method to achieve that is to add a Directional Light into the environment. When the Directional Light is selected, the mobility in the Details Panel should be changed to moveable. Holding the keys Ctrl and L simultaneously enables the option to adjust the direction in which the light shines. The standard daytime settings are set to be bright enough, however for a nighttime scenario the directional light was excessively bright. The Details panel includes an option to adjust the intensity of the light. When the slider of the intensity is in the lower range it results in a cooler and blue color temperature, whereas the slider being in the higher range makes the color temperature warmer and yellow.

To discover the answer to the question how proper lighting can be achieved in a nighttime scene within Unreal Engine (Unreal Engine, n.d.) without inducing moiré artifacts, the researcher started by scanning existing literature to gain a broader understanding of what causes moiré on LED walls and possible strategies to prevent it. Relevant background information was gathered in Chapter 2.3.

From previous experience with virtual production shoots that both the researcher and the interviewed industry experts have, it was a known fact that LED walls do not handle or display darker tones very well. In previous scenarios involving dark environments with limited physical lights, moiré artifacts were evident in the shot during filming.

Chapter 2.3 contains a multitude of strategies to prevent or limit moiré artifacts during production, such as using filters, moving the camera back, changing the depth of field. Additionally, post-production strategies such as using blurring or smoothing tools in editing software was recommended.

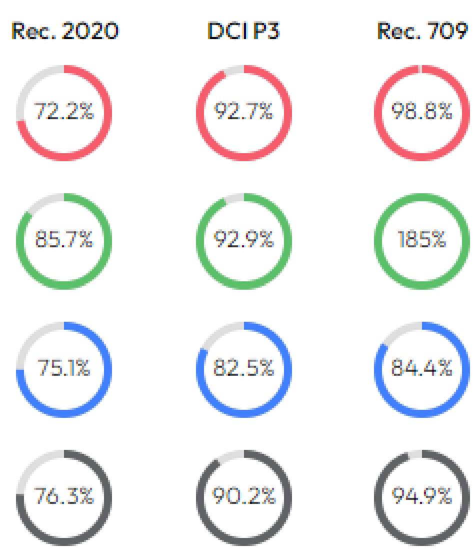
Given the difference between the colors and brightness of the environment on a laptop screen compared to the LED wall, the researcher initially created the virtual nighttime lighting on a laptop screen transferring the environment on the LED wall. The image on the wall displayed lower contrast and appeared dimmer than on a regular computer screen.

During the testing phase, the researcher explored multiple practical suggestions from articles and the interviews with industry experts. Instead of following the inclination to use limited physical lights for a dark scene, the researcher used the same number of lights as utilized for a daytime scene and instead adjusted the aperture on the camera to a higher value to make the shot appear darker. Additionally, the researcher recorded multiple takes of the same shot as moiré showed up once or twice when the camera accidentally focused on the wall. If moiré artifacts can be prevented during production, significant time can be saved as it then does not need to be fixed during post-production.

6.2 Limitations

This research was conducted over the span of five months, which created a time constraint and meant that during the testing phase only two techniques could be tested, and a limited number of participants could be found. The results of this study might have differed if the sample of industry experts had been bigger and if it had been conducted internationally. Additionally, the Vicon system (Vicon, n.d) was not operational for two entire days. This meant that camera tracking was not an option, and the environment was essentially frozen on the screen. Consequentially, testing out a lighting setup and making needed changes to the environment or set was not possible. A limitation related to the previously mentioned issue is that BUas currently only has one expert employed with specialized technical knowledge to remedy errors with Vicon (Vicon, n.d). . Another limitation is the color inaccuracy of the LED wall; the LED wall has a limited color spectrum, with peaks solely in red, blue and green. Figure 16 shows the color accuracy of three different color spectrums that are available for the LED wall at the XR stage at BUas; Rec. 2020, DCI P3 and Rec. 709. The figure shows the color accuracy that the LED wall has of red, green, blue and the overall level of accuracy, which are the bottom black circles. This reveals that using Rec. 2020 would mean that the colors that the wall displays are only 76.3 percent accurate, with DCI P3 it would be 90.2 percent accurate and with Rec. 709 it would be 94.9 percent accurate.

Figure 16 *Color accuracy LED wall XR Stage BUas.*



As mentioned previously in Chapter 5, to be able to duplicate the technique described by Jendrisak, multiple ARRI lights (ARRI, n.d.) hanging from the ceiling were necessary. The XR Stage is not equipped with these lights and therefore the researcher needed to make adaptations during the testing phase to make it feasible. Another limitation was the steep learning curve; the researcher had to execute a variety of tasks in Unreal Engine (Unreal Engine, n.d.) with no prior knowledge or experience to be able to have an environment to use for testing. Additionally, there was no crew available, which meant that the researcher had to take on multiple production roles including writer, director, producer, set designer, light designer and camera operator. The consequences of this included less time to conduct the testing and less extensive filming and set design. Furthermore, the environment used during the testing phase of the Best Practices based on Experience document was a limitation. The environment did not contain any individual lights, which meant the participants could not test out the practices surrounding the virtual lights in Unreal Engine (Unreal Engine, n.d.). Due to the time limit, it was not possible to implement the suggestions the participants made to enhance the quality of the Best Practices Based on Experience document. However, that does not take away from the fact that it has already been proven useful and could still be implemented at this point.

6.3 Further Recommendations

The proposed recommendations for both industry and further research regarding this research topic intertwine. The underlying reason for this is because the people that work in the virtual production industry and utilize the necessary technology often research and strive to develop innovative tools that can be implemented in the process of virtual production projects.

After an extensive literature scan and interviews with industry experts, it emerged that a multitude of industry professionals are currently researching or are in the process of developing innovative tools to match the physical lighting with the virtual lighting. An example is an application that is currently in development called CyberGaffer, which is a set of plugins for 3D software accompanied by a standalone application (CyberGaffer, 2024). The plugins capture light information from the virtual scene and transfer it to the application, which then tune the physical lights accordingly (CyberGaffer, 2024). The main recommendation would be to continue research in this topic and considering the development of an application that could make the matching of the lighting easier. In the case of creating an application during research, it would be recommended to include researchers with a bigger technical background or programmers to make the development feasible.

As this research could be relevant to any studio or production using LED walls or other virtual production technology, it is recommended to conduct this research not specifically to one studio like this study did. Instead, it is recommended to include studios and professionals internationally to have the ability to gain more diverse data and possibly have a different outcome.

Appendix A

A.1 Exploratory Interviews

[Interview Jendrisak]

[Interview Boots and de Bilde]

A.1.2 Consent Forms Exploratory Interviews

CONSENT FORM INFORMAL INTERVIEW

RESEARCH TITLE: Capstone Research report Shanna Koopmans

I Teodor Jendrisak (your full name) provide consent to the following research institutions:

Breda University of Applied Sciences,

to use my data within the above-mentioned project.

I have been informed about the research project entitled [title] and have been requested to share previously collected data with the researchers involved.

I have been informed about the goal of this project and I have had the opportunity to ask the research team any questions which may arise about the research and my participation.

I understand that my participation in this research is voluntary, I am free to refuse to participate and free to withdraw from the research at any time. My refusal to participate or withdrawal of consent will not affect my position and my relationship with the institutions involved.

If I have any enquiries about the research, I can contact Shanna Koopmans (201750@buas.nl), the responsible researcher or if any concerns or complaints regarding the way the research is or has been conducted, I am free to contact Utrecht's Dr Mata Haggis-Burridge (haggis.m@buas.nl), ethics board member at BUas.

By signing below, I am indicating my consent to:

- Provide access to the previously collected data regarding [student experiences at BUas].
- Having the collected data shared and to be used to evaluate and improve the [education within BUas].
- Being contacted if further clarification is necessary to investigate statements present in the collected data.
- The data is to be handled by the project leader prior to full anonymization to enable further enquiries if required. All data presented outside of the researcher team will be presented in an anonymized way.

I understand that the data collected from my participation will be used for the purpose of this research and will be securely stored, and I consent for it to be used in that manner.

Signature

Toodor Jendrisak

....

Date 15.04.2024 Place Ede, NL

CONSENT FORM INFORMAL INTERVIEW

RESEARCH TITLE: Capstone Research report Shanna Koopmans

I PAUL BOOTS (your full name) provide consent to the following research institutions:

Breda University of Applied Sciences,

to use my data within the above-mentioned project.

I have been informed about the research project entitled [title] and have been requested to share previously collected data with the researchers involved.

I have been informed about the goal of this project and I have had the opportunity to ask the research team any questions which may arise about the research and my participation.

I understand that my participation in this research is voluntary, I am free to refuse to participate and free to withdraw from the research at any time. My refusal to participate or withdrawal of consent will not affect my position and my relationship with the institutions involved.

If I have any enquiries about the research, I can contact Shanna Koopmans (201750@buas.nl), the responsible researcher or if any concerns or complaints regarding the way the research is or has been conducted, I am free to contact Utrecht's Dr Mata Haggis-Burridge (haggis.m@buas.nl), ethics board member at BUas.

By signing below, I am indicating my consent to:

- Provide access to the previously collected data regarding [student experiences at BUas].
- Having the collected data shared and to be used to evaluate and improve the [education within BUas].
- Being contacted if further clarification is necessary to investigate statements present in the collected data.
- The data is to be handled by the project leader prior to full anonymization to enable further enquiries if required. All data presented outside of the researcher team will be presented in an anonymized way.

I understand that the data collected from my participation will be used for the purpose of this research and will be securely stored, and I consent for it to be used in that manner.

Signature

[signature]
....

Date 12-5-2024 Place ROTTERDAM.

CONSENT FORM INFORMAL INTERVIEW

RESEARCH TITLE: Capstone Research report Shanna Koopmans

I Pim de Bilde provide consent to the following research institutions:

Breda University of Applied Sciences,

to use my data within the above-mentioned project.

I have been informed about the research project entitled [title] and have been requested to share previously collected data with the researchers involved.

I have been informed about the goal of this project and I have had the opportunity to ask the research team any questions which may arise about the research and my participation.

I understand that my participation in this research is voluntary, I am free to refuse to participate and free to withdraw from the research at any time. My refusal to participate or withdrawal of consent will not affect my position and my relationship with the institutions involved.

If I have any enquiries about the research, I can contact Shanna Koopmans (201750@buas.nl), the responsible researcher or if any concerns or complaints regarding the way the research is or has been conducted, I am free to contact Utrecht's Dr Mata Haggis-Burridge (haggis.m@buas.nl), ethics board member at BUas.

By signing below, I am indicating my consent to:

- Provide access to the previously collected data regarding [student experiences at BUas].
- Having the collected data shared and to be used to evaluate and improve the [education within BUas].
- Being contacted if further clarification is necessary to investigate statements present in the collected data.
- The data is to be handled by the project leader prior to full anonymization to enable further enquiries if required. All data presented outside of the researcher team will be presented in an anonymized way.

I understand that the data collected from my participation will be used for the purpose of this research and will be securely stored, and I consent for it to be used in that manner.

Signature

……………………………………………………………………

Date 10 May 2024 Place 's-Hertogenbosch

A.2 Consent Survey

Breda University OF APPLIED SCIENCES

Hi! If you're filling in this survey, that means that you have read the 'best practices based on experience: lighting' document and tested it out. The purpose of this survey is to pinpoint how useful this document could be for students and whether it is understandable. There are no right or wrong answers, so please answer the questions with honesty.

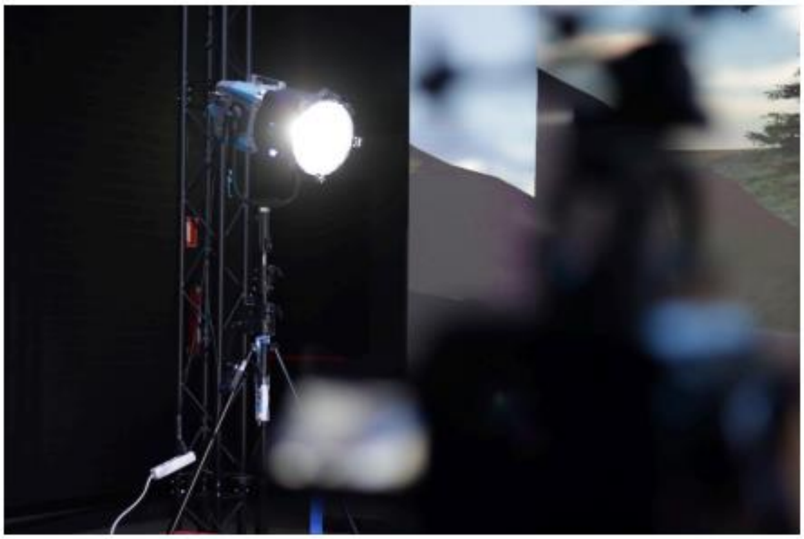
This document and survey are a part of a Capstone research report and the results of this survey will be discussed and showed in the research report. Your answers are fully anonymous.

Thank you for your participation!

- ○ I have read the text above and consent to my answers being processed and described in the report.

A.3 Best Practices Based on Experience Document

Breda University of Applied Sciences



BEST PRACTICES BASED ON EXPERIENCE:

LIGHTING

Created by:
Shanna Koopmans

Introduction

This document essentially contains practical recommendations given by people with experience in lighting for virtual production shoots. The information is split up into different sections, the overarching themes are named in the colored headings. These practices are meant to help students with lighting their set, hopefully able to remind them of small things that are easily forgotten or not thought of in the first place.

This document is part of a capstone research report, the research being about finding a technique to best match the physical lights with the virtual lights at the XR Stage at BUas. Interviews with industry experts and conversations with other people with experience led to the realization that there were a lot of insightful suggestions. Given my conviction that acquiring a comprehensive understanding of those practical recommendations would benefit the process of lighting design for students during virtual production projects, I created this document.

Unreal Engine
- **You can manipulate your virtual light sources by using flags** just like you can do with your lights on set. You can do this by using a cube and making it an absolute black material. This will ensure that it will not reflect or allow any light through and can make your light only hit specific items in your virtual environment if that is what you're aiming for. - **Add as little lights as possible**, move them around and manipulate them before you add more. Too many light sources can cause interference and will cause errors in your environment.

Light Spill
- **Never point a light directly at the screen.** When you set up a light, there is a big chance that there is light spill on the LED wall. Light spill can make your image on the wall look greyish or washed out. To check whether you have light spill, you go to Helios on the computer and on the bottom left there is a button called Blackout. When you press this, the wall will turn black, and you will be able to see the light on the wall. If you have multiple lights present on set, you will want to check them one by one to see what effect they have. **To get rid of or at least minimize the amount of spill on the wall, you can set up c-stands with black flags next to the light to block the light from spilling.**

Color Temperatures
- **Matching the color temperatures is incredibly important.** Something that can be useful in achieving this is DMX. - **If you don't know what the color temperature of a certain light source would be, look it up instead of guessing.** Using the color temperature that that light source would have in real life will help with making your scene look more realistic.

Lighting Set/Actors
- **Focus on light hitting the short side of an actor's face and wrapping it around.** You can do this by starting with a harder light and placing a softer light next to it, which will wrap the light around your subject. - **Harsh shadows on a person's face are rarely flattering.** Unless it truly makes sense with the place of the scene/the amount of life, soften your lights by placing white flags in front of them or make use of filler lights to fill some of those harsh shadows. - If you're using hard lights, you have to keep in mind that it is more difficult in LED volumes due to the diffused light from the screen. - When you're **struggling to figure out what the lighting in a specific situation should look like**, for example how light would look like through a window of an old building, try to visit a similar real location to just look at what light naturally does. This will make replicating that easier, and your shot will look more realistic. - **Break it into pieces**: Look at what each light does individually to your set and change it accordingly before adding more and more. - **Blending the virtual and physical is one of the most important things to make your scene look realistic**. Achieve this by placing your physical lights at a similar angle as your lighting in Unreal Engine and preferably at the same color temperature.

Camera
- If you're figuring out your lighting setup, always **check how it looks through the camera or on the monitor instead of directly looking at your scene in front of you**. A camera sensor perceives light, and colors differently than the human eye does and since your final footage will be shot with the camera, it's important that it looks best through the camera's view. - **If you have a scene where it is supposed to be dark, you should still light your set properly**. Instead of minimizing the number of lights, try changing the t-stop (aperture) on the camera to a higher number. This can prevent moiré and that your footage turns out to be too dark. It's always easier to darken it in post-production than to attempt to make it lighter.

LED Wall
- **The LED Wall should not be your main source of lighting**. If you only use the ceiling and wall to light a person, they will have a reddish or pinkish color because the LED wall has a narrow color spectrum only with peaks in the colors red, blue and green. - To **change the brightness of the wall**, you can go to Helios on the computer and on the bottom left there is a button named 'Image Settings'. In there you can easily adjust the brightness of the wall.

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