How can Virtual Production be used to create Flexible and Modular Pipelines for Short Film and Music Video Creation?

An exegesis presented in partial fulfilment of the requirements for the degree of

Master of Creative Enterprise
At Massey University, Wellington, New Zealand

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Year of lodgement: 2023

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01_Abstract

Virtual Production encompasses a selection of emerging techniques and technologies for audio-visual content creation. Virtual Production requires a large depth of knowledge in order to be implemented into production pipelines. This thesis explores various virtual production tools and techniques through the generation of multiple creative projects, including short films and music videos.

The goal of this research is to explore the research question: How can Virtual Production be used to create Flexible and Modular Pipelines for Short Film and Music Video Creation. This question will be explored through the development of various pipelines for a wide variety of creative projects. The effectiveness of these pipelines is evaluated through three key metrics: flexibility, modularity and cost-effectiveness.

Using a practice-led research methodology, flexibility, modularity and cost-effectiveness are evaluated through the completion of multiple subsequent creative projects. Each subsequent project builds on the knowledge gained from the previous project, allowing the knowledge gained to accumulate.

This research project contributes to the Virtual Production landscape by providing an insight into how Virtual Production can be implemented into multiple different projects to enhance the creative process, with a particular emphasis on small-scale and small-budget projects, of which there is currently limited literature.

Figure a: Behind-The-Scenes of A Virtual Production Shoot

02_Introduction

'Virtual Production' has emerged at the forefront of modern-day audio-visual content creation. By leveraging the tools and techniques made possible by modern technological advancements, Virtual Production has allowed creators to unlock new ways to tell a story. Despite the industry experiencing a rapidly growing interest in Virtual Production[1], there is still a distinct lack of knowledge and expertise within the Short Film and Music Video space as to whether it is a viable tool for production.

At its core, Virtual Production is an approach to filmmaking (of all forms) that utilizes 3D software, virtual camera systems and motion capture technology to visually interact in some way with a real-time digital environment[1]. This can take many forms, ranging from something as simple as using a virtual camera system to explore a digital environment, to as complex as rendering a photoreal digital environment onto an LED Volume integrated with a physical set. Virtual Production can also be applied to all stages of the production process.

Figure b: Live Action Animation with Virtual Production

Key Terms

Virtual Production – The use of 3D Software, Virtual Camera Systems and Motion Capture Technology to visually interact with a real-time environment.

Real – Time Rendering – Real time rendering is a technology that allows a digital world to be brought to life quickly enough to respond to actions in real time. It is the driving technology behind video games and eliminated the need to wait hours for a render to be complete so that a creative can see the final product.

Virtual Camera – A Virtual Camera or Virtual Camera System is a real-world camera that is tracked digitally in 3D space, which provides a view into the digital world.

LED Volume – A series of Modular LED Panels, connected to form a large wall-sized array – often in the form of a large curve or corner.

Photogrammetry - Photogrammetry is a method that uses photographs to create 3D models. It works by taking pictures of an object from different angles. Then software analyses the pictures and creates a 3D model of the object by finding matching features and triangulating distances.

In – Camera VFX (ICVFX) - In-camera VFX or real-time VFX, is a technique used in filmmaking to combine practical and digital effects in real-time during the shooting process. It allows filmmakers to see the visual effects elements live on set, rather than relying on post-production to add them later.

Current Landscape

Big Budget Hollywood productions have popularised Virtual Production, with companies such as ILM (Industrial Light and Magic) and Weta FX investing millions of dollars into building out Virtual Production capability.

There are a multitude of reasons for the increasing popularity of Virtual Production as a tool for filmmakers, including the following:

Collaboration

As modern filmmaking pipelines have developed, much of the creative process has shifted from production into post-production, due to the rise of computer-generated visual effects. This has made it increasingly more difficult for directors, actors and other key creatives involved in production to express their creative input into a project, often working in bland green or blue screen environments. Virtual Production brings a lot of the creative decision making back into production by allowing actors, directors and other key creatives to see what the final product might look like much earlier in the process – leading to a more cohesive collaborative experience.

Figure c: Production Crew on a Virtual Production Shoot

Cost

Shipping large productions across the globe to shoot locations is an expensive process, with up to 40% of a productions total below the line budget being put towards location related expenses (Transport, Travel, Fees, etc.)[2]. Travel-reliant projects are vulnerable to unpredictable global events such as pandemics, as was seen during the 2020 Covid-19 pandemic. During this time many location-based productions were halted, leading to long release delays and other knock-on effects[3].

Climate

In a cost breakdown done by UK studio 'Quite Brilliant', the carbon offset cost per hour on average was only $9USD for a Virtual Production Shoot vs $1154USD for on location[3]. As global warming becomes a larger concern, reducing carbon emission is a large motivator for Virtual Production technology.

Technical Benefits

Virtual Production allows the fine control of the shoot environment on a level that cannot be matched with a location shoot. Location shoots are venerable to a multitude of environmental factors, such as the weather, lighting conditions, etc. One of the common use cases is to allow for creatives to shoot at sunset, which on location may only last minutes. Using Virtual Production, a sunset that is infinitely long can be created.

Despite the large shift in the feature film industry, Virtual Production technology remains largely unproven for independent short film and music videos. There are examples such as SHADE's 'No Other Way' music video[4] and Katy Perry's 2020 American Idol Performance[5] that prove that Virtual Production technology can be leveraged effectively to create this type of content, but the budgets of these productions do not fall under the 'independent' category.

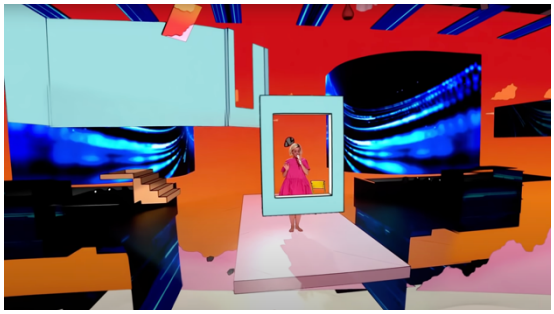

Figure d: Katy Perry 2020 American Idol Performance

This shows that there is a gap in the literature that provides an insight into the advantages and disadvantages that Virtual Production in its current form has in relation to Music Video and Short Film creation. This research attempts to address that gap.

Personal Position

From a young age I have been deeply invested in technology, and as an avid supporter of independent productions in the Wellington region, I am searching for a way to link these fields together. I believe that the use of Virtual Production technology on small scale projects will bring enormous benefits, not just to the productions themselves through reducing cost, resource overheads and broader creative freedom, but to Aotearoa as a whole, by boosting the creative potential of audio-visual production nationwide.

03_Literature Review

Types of Virtual Production

Virtual production is an umbrella term that encompasses a broad range of different technologies and techniques. The core difference of a Virtual Production pipeline when compared to a 'traditional' screen production pipeline is the usage of real - time 3D graphics along with virtual camera and motion capture technologies, which allows creators to view the final image during production, rather than having to wait until the post - production phase[1].

Another form of Virtual Production is to combine real-time camera tracking and compositing, with a traditional green screen. This scenario uses the same processes as the LED wall version. However, instead of the 3D scene being rendered directly onto the background and captured by the camera, the camera captures an image, the green is keyed out, then the live action plate is composited on top of the digital scene in real time[6].

Removing the live action component of the two previous Virtual Production workflows leaves a method that can be used for previsualization of scenes. This method is often used to give creators a better understanding of what things will look like once production starts. There are multiple forms of Virtual production previsualization. The most common form is to use a Virtual Reality headset to allow creatives to explore the digital world. This is much like a location scout in real life, but in virtual reality[7].

Each Virtual Production method has its own pros and cons. LED Wall production has an advantage over Green Screen production as you no longer have to 'jump through hoops' to achieve the desired lighting effects, specifically for things such as reflective objects that would require expensive postproduction adjustments to look nice[8]. On the contrary however, Green Screen production is much cheaper and better for the environment than using an LED Wall.

Virtual Production without the use of an LED Wall is particularly interesting as it has uses that extend beyond that of a live action shoot, and into other areas such as the production of CG animated content and more.

Virtual Production Workflows

In order to understand how Virtual Production can be used to make more flexible and modular pipelines that can be applied to smaller scale short film and music video productions, I have looked at existing pipelines used by larger production companies.

More and more companies are dipping their toes into the Virtual Production space, creating bespoke pipelines to fit their productions. The earliest example of Virtual Production employed was in James' Cameron's Avatar (2009) where a simulcam (real camera tracked into a digital

world) was employed to provide the director a real-time view into the digital world that would eventually be composited into the background[1].

More recently, production companies such as ILM, MPC, Wētā FX and more have been developing bespoke pipelines to suit their existing workflows. Wētā FX was one of the earliest adopters of Virtual Production, using a Virtual Production system in Avatar (2009), where director James Cameron leveraged the technology to direct actors on a MoCap stage while viewing their performance in the context of the 'Pandora' environment in real-time[9].

Wētā originally used Unreal Engine as the core of their pipeline, before developing their own real time renderer. In late 2021, Wētā FX's tools, pipeline and R&D talent was acquired by Unity Technologies - which could mean a shift in the workflow once again[10].

ILM has also developed their own Virtual Production workflow over the years. In 2019 the Research and Development that ILM had been doing culminated in the 2019 series 'The Mandalorian'. Using Unreal Engine and an LED Stage, ILM were able to create 'StageCraft' which is a complete Virtual Production platform. Following on from this they then developed a completely in-house approach to Virtual Production with Stagecraft 2.0. Stagecraft 2.0 marks a departure from Unreal Engine, adopting an ILM developed renderer 'Helios'[11].

Figure e: ILM's Stagecraft Virtual Production Set

MPC has developed a Virtual Production pipeline called 'Genesis', which is one of the few companies that leverage Unity to provide the real-time render capability[12]. Genesis is an interesting example, as they have specifically focused on integrating Virtual Production into their existing workflows through their 'Asset Management System'. In this 'High Budget' sector of production companies, there is a very apparent theme of taking an in-house approach towards Virtual Production tooling. ILM and Wētā FX already have completely proprietary solutions, with MPC being the only company to use a commercially available renderer (Unity) - however with a deep integration with their own proprietary tools.

Tertiary institutions are also exploring virtual production workflows. Savannah College of Art and Design (SCAD) have designed and developed a curriculum for Virtual Production [13]. SCAD implements a workflow that utilises a Disguise to Unreal Engine workflow. Disguise is a 'fully integrated ecosystem of hardware and software' that powers XR stages such as an LED Virtual Production volume[14]. SCAD's focus is on developing a method of teaching that prepares students for a production environment using Virtual Production. Highlighted in the paper they released is the fact that teaching Virtual Production skills requires a 'significant departure from the production method engrained in most film programmes.' Outside of SCAD, there are many tertiary institutes looking to start, or rework existing screen programmes[15].

The large-scale nature of these productions/operations clearly showcase the need for bespoke pipelines to be developed. For most large-scale production companies, this comes in the form of a research and development team that can dedicate resources to create a pipeline that works to a high standard of quality. There a very few examples of small-scale productions doing this, as the resources (money) required is too high to fit their budgets.

Tracking Methods

Camera tracking is a key component of any Virtual Production pipeline. The primary way that a tracked camera is achieved is through motion capture. Motion capture is "...the process of recording human movement as computer interpreted data"[16]. This data can then be translated into digital motion for virtual objects. In the case of Virtual Production, the movement of the real camera is tracked and translated into digital motion for a virtual camera.

With advancements in technology, there are now a plethora of options available at different price points, all with different pros and cons. MoSys and Halide FX are two optical tracking systems that rely on 'markers' placed on the ceiling of a shooting environment, as explained by Mark Sawiki and Juniko Moody in the 2020 book 'Filming the Fantastic with Virtual Technology'[17]. This type of optical tracking solution requires a separate 'tracking camera' to be placed on top of the 'main camera'. Both the MoSys and Halide FX systems contain this tracking camera, however they begin to differ from there. Halide uses a series of printed targets, containing three different sized markers that the tracking camera can use to track movement. MoSys however, uses a series of retroreflective points to track.

Figure f: MoSys System with Retroreflective Markers

The MoSys solution lights the retroreflective markers using an Infra - Red light on the tracking module itself, which removes the need to light the ceiling of the set. However this can

introduce some tracking artefacts if there are bright lights or reflective surfaces in view of the tracking camera[17].

Vicon and Optitrack are two solutions that also utilise Optical Tracking. Instead of the trackers being located on the ceiling, the trackers are located on the camera. This type of optical tracking uses multiple cameras to 'track' reflective markers attached to objects, such as a camera. Vicon and Optitrack both provide extremely accurate tracking, which is scalable to the size of the tracked volume required - but often come at increased cost when compared to other tracking systems[1].

Another Optical Tracking option at a low cost is the HTC Vive VR system. This is a consumer-focused system, which reduces the cost when compared to other commercial tracking solutions. The HTC Vive is almost as accurate as other solutions (within 2mm) and is equally as responsive (~20ms), which makes it the perfect option for a lower budget Virtual Production solution [18].

As demonstrated above, there are a multitude of tracking solutions available to service Virtual Production pipelines, from the gold standard industry solutions such as Vicon and Optitrack, down to mid-range solutions, Halide and MoSys, to the consumer grade HTC Vive Mars. The Vive is particularly notable, as it shows that the technology behind Virtual Production has reached a point where it is available to small scale short film and music video productions. The limiting factor these productions have is the knowledge required to implement this technology.

Rendering

Another key component of a Virtual Production pipeline is the renderer. As Virtual Production is relatively new, it utilises the power of a game engine that allows us to see our computer generated imagery in real time [19] The two big players in the field currently are Epic Games' Unreal Engine, and Unity Technologies' Unity. The key differences between each engine are outlined in an article by Lukas Niklaus called 'Unity vs Unreal: Which Fits You Best'. Niklaus explains that both companies have spent considerable investment into VP tools for their respective editors, but Unreal Engine currently holds the largest market share. The choice eventually comes down to extremely small factors, such as which coding language a user is most familiar with, or what other pieces of software are employed in a pipeline - and whether they function better with a particular engine.

Related Creative Works

Virtual Production was first used in James Cameron's 'Avatar (2009)'. Cameron used a 'simulcam' system to give the director (himself) a direct view into the digital world through a tracked monitor. Since the film is completely CG animated, the actors were acting in Motion Capture suits. This meant that the performance from the actors could also be viewed in real time in the monitor. This enabled Cameron to be more confident in the creative decisions made

during production. The actors were also able to see how their performances looked within the context of the story world. Over time, this technology has trickled down to where it is now available to most smaller budget productions.

LA Based production studio ‘Corridor Digital’[20] produced a web series called ‘Son of a Dungeon’[21], which employed similar virtual production methods to Avatar throughout its two released seasons (third planned). ‘Son of a Dungeon’ follows a group of friends playing the tabletop RPG game ‘Dungeons & Dragons,’ which uses a diorama of miniatures to represent the players traversing through a fictional world on the tabletop. Corridor’s team then utilized photogrammetry on the physical tabletop diorama to bring the game board into Unreal Engine. From this point they then used Virtual Production with a green screen and live composite to shoot scenes from their gameplay in live action, with the tabletop players dressed up in-costume to play their fictional game characters.

The motivation to use Virtual Production was so the crew could see a final render in real time, with a live green screen key and composite, as well as recording tracking data directly into Unreal Engine[22]. This culminates in a fast, efficient workflow which allows a small production studio like Corridor Digital realise bigger creative visions. Rather than having to manually track each green screen shot, do the keying, line it up with a digital plate and composite it, they simply render the already motion tracked digital plate from Unreal Engine, key the shot from the camera and comp it together. This eliminates hours of painful manual work (tracking, etc) which can now be used for more creative parts of the process like the edit. Another benefit is that every single take has tracking information, which allows every take to be viewed in a final state before making the decision on which to use in the edit.

Figure g: 'I Will Make the BEST DnD Show on the Internet' Corridor Digital (https://www.youtube.com/watch?v=k9-KMsrq1rk)

This workflow clearly shows what is achievable for smaller scale productions, however Corridor Digital has a deep background in researching new filmmaking techniques which has allowed them to develop a Virtual Production workflow – their research and development is what sets

them apart from other studios and is a core part of their value.

The next step up from live green screen is the in-camera VFX workflow employed on the set of Disney's 'The Mandalorian'. 'The Mandalorian' popularized the use of in-camera VFX through a technique called 'StageCraft.[23]' The main component of StageCraft is a massive LED video wall called 'The Volume.' The Volume surrounds the set and displays high-resolution digital backgrounds, landscapes, and other elements in real-time. During the production of 'The Mandalorian,' The Volume was used in conjunction with physical set pieces to create an extremely convincing effect when viewed through the camera. There are multiple benefits of this technique over a green screen virtual production workflow, such as real time lighting and reflections, no need for keying and compositing and a more immersive world for actors to act in.

These implementations show that production companies find Virtual Production to be a viable tool, investing large amounts of time and money into research and development. For smaller scale productions to benefit from Virtual Production, they need a way to tap into the required knowledge and resources required to use Virtual Production.

04_Methods

The predominant method of development for most virtual production pipelines is to take an iterative approach. Both Corridor Digital[22] and ILM[11] have released behind the scenes content showing their development process. With each completed 'test' they gained more and more knowledge until they reached a product that was completely production ready.

Adapting this into an academic context has led me to use a practice led action research approach. Action Research refers to the cyclical nature by which I have undertaken subsequent projects. Action Research emphasizes a cycle of participation, reflection and the use of practical knowledge to gain new insights. This allows multiple projects employing Virtual Production to be evaluated in a cyclical nature, with each project iteration providing new knowledge. The project iterations are not repetitions of the same project, rather they are completely different projects each time, which provides new scenarios to test different practical interventions.

Previous Work

I worked on three Virtual Production related projects prior to the commencement of this exegesis, which consisted of one real – time animated short film and two interactive exhibitions. The knowledge I gained from these prior productions consisted of foundational knowledge in Virtual Production implementation in Unreal Engine. This enabled me to dive straight into the technical challenges of the projects outlined below.

Project 1

Building on the knowledge gained throughout my undergraduate studies, I set out to discover whether Virtual Production tools and techniques could be used to create a live action short film, with emphasis on the flexibility and modularity of the overall pipeline.

This took the form of a collaboration with noted Director Jonathan King. King had written a script for a short film and intended to use Virtual Production components accessible as Massey University, Wellington to shoot a short scene. This was designed as a test of whether Virtual Production would be viable for the rest of the film. A Vicon Tracking System was used to track the camera, a Green Screen Studio was used as the Comp/Display Medium and Unreal Engine as the real-time renderer.

In pre-production, the 3D environment was modelled from scratch by King, then imported into Unreal Engine and prepped for shooting. Using the specific technical knowledge gained from the past three years of learning, this was a very smooth process which allowed plenty of room for creative choices to be made in a seamless fashion. I was able to utilize a VR headset to give King a better grasp of how the virtual world was laid out.

During production, I used Unreal Engine's built in 'composure' tool, which allowed real time green keying and comping. This allowed the cast and crew to see in real time what the final product would look like, including fine details such as lighting direction and positioning in space. This restructured the workflow previously established for VFX heavy films. Rather than being stuck with the choices made on-set throughout production (such as lighting direction, intensity, temperature, etc.), choices could be made in reference to the digital set during production.

A direct example of this was the ability to reconfigure/move set elements shot by shot, which is a common practice in traditional live action filmmaking. I was often moving walls around in order to give the room more space or shooting through a wall to give a more telephoto look – both of which are techniques that could not have been replicated in real life. Lighting decisions could also be made spontaneously by either tweaking the physical or digital set. Camera angles could also be chopped and changed at the click of a button.

I had several issues during production, mainly tracking instability and poor-quality live comps. The tracking instability was caused by improper setup of the Vicon Motion Capture cameras. Previously all motion capture projects had been in a room where the height of the cameras was 2m. In this room I was very familiar with intricacies of calibrating the system. Moving the cameras to the green screen studio meant rigging them at 4m – double the previous setup. I failed to consider the differences in setup this change would require, which resulted in very subpar camera tracking. The poor-quality live comps were due to a bug in the latest version of Unreal Engine, which was later resolved in an update.

Despite the technical issues during production, viewing the digital composited scene while shooting was a great tool and it allowed for more informed creative decisions. This improved workflow also carried on to postproduction, as the digital composites were recorded and could be used in the edit immediately after shooting, just like a traditional live action shoot. Since the camera motion was also recorded, it means the editor could make shot and cut choices much later in the edit, since the time taken to manually motion track a shot is removed.

Figure h: Behind the Scenes of 'Birds'

Project 2

Project 1 showed benefits to using Virtual Production, which lead to the adoption of VP for ‘Frisky’, directed by student Stevie Goodwin.

Goodwin is very interested in the collaborative process behind filmmaking. They were struggling to storyboard for their upcoming shoot. The Performance Capture stage was chosen, along with replica 3D environments (matching the live action shoot location) to storyboard in real-time – allowing the DOP, Director and stand in actors to all collaborate in creating a storyboard.

The setup consisted of the Vicon motion capture system, a wired monitor with tracking markers on it and a computer with a DeckLink card (a media capture device for getting live video feeds in and out of Unreal Engine). The Unreal Engine scene then took the tracking information from the Vicon system, and rendered out a live feed to the monitor which could be carried around the room to view the digital scene.

The final piece of the puzzle came in the form of two stand-in actors in MoCap suits, which had their motion mapped onto Unreal Engine Metahumans that were roughly created in the image of the actors for the live action shoot. Metahumans are humanoid digital doubles that can be customised to very fine detail and are designed to work seamlessly within Unreal Engine.

The landscape for the ‘Virtual Storyboarding’ was created from LiDAR data collected from Land Information New Zealand’s (LINZ) publicly available repository. Since ‘Frisky’ is set on a section of land located in Hawkes Bay New Zealand, the exact geography of the shoot was able to be inserted into Unreal Engine, providing a reference that is accurate on a 1-1 scale. An automatic landscape material driven by splatmaps created in SideFX Houdini was then used to create textures and scatter grass/foliage that roughly match the physical location.

Using this approach, Stevie and their team were able to achieve a cohesive vison on how they would shoot the film once in production. The collaborative environment allowed for rapid problem solving, with multiple members of the crew able to provide creative input at any moment.

Figure i: Live Storyboard Results

The benefits of using Virtual Production in this scenario reinforced discoveries made in Project 1. Set elements were able to be moved around at will, which allowed Goodwin and their team to have an extremely clear idea of what they would have to do on location for shooting, as well as whether certain shots would be physically possible or cost effective to conduct.

Goodwin and their team then used the resulting live action storyboard to create a shot list that could be taken out on location while shooting. The shot list allowed them to have full confidence that if they ticked off every item, they would have enough coverage to edit together a complete narrative.

Project 3

Project 3 came in the form of another collaboration with Jonathan King, as well as singer/songwriter Delaney Davidson. The creative output was a music video directed by King.

Pulling from the experience of Project 2, we began by digitally generating the environment where the shooting would take place. King had a strong concept of what the final product would look like, which lead to a smooth pre-production workflow. The technical knowledge gained in Projects 1 and 2 allowed the desert western style landscape to come to life with ease. The LiDAR technique used in Project 2 allowed me to bring the real-life location reference (Port Hills, Christchurch) provided by King directly into the project.

The benefits of working in this environment were that creative choices could be made effectively and efficiently. King often had valuable creative input, such as 'Can we move that mountain back a bit', which could be done immediately without having to wait for a fresh render or second modelling pass.

When working with King in Project 1, we used a VR headset as a tool to virtual 'location scout' to plan the shoot, however since that previous production, King had spent a lot of time in 3D software packages and was very comfortable navigating the digital world through the 3D viewport of Unreal Engine. Creatives will have more hands-on control of the virtual world as they gain familiarity with the tools over time. I still believe that a VR headset is an important tool to introduce to people exploring Virtual Production workflows. It allows them to experience the digital world in a way that is more familiar to the way they interact with the real world. This is an easier introduction than trying to navigate a 3D viewport on a 2D screen.

During production I utilized the same Vicon Tracking system that was used in Project 1 and 2, and the same green screen studio as used in Project 1 with King. Previously, the Vicon tracking system introduced tracking noise. This was due to the improper setup of the optical tracking cameras. The green screen studio has a 5m ceiling truss that I mounted the cameras on. Being so far off the ground means that the lens element of the optical cameras needs to be zoomed in to still get accurate tracking information from the retroreflective markers placed on the camera. Previously I had not correctly zoomed the cameras for this space. Having the knowledge from Project 1 allowed me to make more informed decisions when setting up the tracking system. This gave a clean tracking result.

The live chroma keying of the green screen to provide a real time composite with the digital environment was previously a problem in Project 1. For this project I was able to use the composure tool within Unreal Engine 5.1 to send the live camera feed through a Blackmagic

Capture Card into Unreal Engine, perform the chroma key, then output a composited image onto both a monitor on the camera, and a TV. This meant that everyone on set had a view of the final composite. The live comp was high quality, meaning that the crew could make informed creative decisions based on they were seeing.

The final benefit of the virtual production process was the speed of post-production. The day after the shoot I was able to export high quality renders for King to start the edit with. I could continue to fine tune the finer details of each shot based on Kings feedback. Notes included direction such as 'adding some shrubbery in the corner of shot 1' and 'Can we make those background hills bigger?'.

Overall the Director found that using Virtual Production was very beneficial, particularly when it came to the creative collaboration. King said that it 'Allowed the creative envelope to extend as far as the artist…' and '…the tools allowed for the creative input to continue for much longer than expected when compared to traditional location based shooting.' These both back up the claim that Virtual Production is a more flexible method of production. When asked how King felt about the process once the final product was completed he said 'I felt incredibly positive about the process… but none of it does it for itself'. This is valuable insight which shows that although VP workflows can allow creatives more freedom, it does not change the amount of effort required to produce something great.

There are still slight issues in this workflow that can be improved upon. One of the crucial learnings in this workflow is that the physical camera lenses need to be calibrated to the digital lens. Every camera sensor and lens paring has a certain amount of lens distortion, and in order to get a digital picture to match we need to know this distortion, and apply it to the digital camera. Unreal Engine has built in tools to calibrate for this distortion, but I was unable to leverage them in the limited timeframe available for this shoot. This resulted in a mismatch between the CG and live action plates. This would only be noticeable if you knew what you were looking for, but still shows that there is room for improvement.

Figure j: Final Composite of 'Stairs to Heaven' Music Video

05_Reflection

During the research I ran into numerous technical challenges while implementing Virtual Production pipelines to each individual project. These challenges came predominantly around fitting all the pieces of the pipeline together. When one piece doesn't work quite right it effects the rest of the process. This can be seen clearly in Project 2 and 3. Project 1 had tracking system issues and Project 3 had incorrect lens calibration.

This attests to the premise of this thesis; that extensive VP experience is needed to conduct these projects effectively. As each project improves my capability, these learnings can be applied to provide benefits to small-scale indie film and music productions so they don't need to pay for them in-house.

Once these issues were ironed out, the benefits of Virtual Production became apparent. Reflection on the key points of the research, flexibility and modularity are discussed below.

Flexibility

The three creative works demonstrate how flexible Virtual Production pipelines can be. This was evident in all three projects.

Project 1 showed the flexibility of working in a digital world, where I was able to move set elements around to create shots that would not be possible in real life. The flexibility to manipulate the shoot environment was a highlight for the Director of this project, 'What I like about Virtual Production is that you are not locked into what you see on the day'.

Project 2 leveraged the power of virtual worlds to provide a playground for Goodwin and their team. Goodwin had the flexibility to place themselves anywhere in the digital world to shoot their digital storyboard, and the speed of which this could be achieved was far greater than a traditional location scout experience.

Project 3 showcased the flexibility of Virtual Production outside of the production phase. Creative flexibility was afforded to King throughout all stages of production, from developing the virtual world in pre-production, modifying it during production, and finally refining it in post-production. The collaboration enabled by this flexibility was especially important for Project 3. The ability for the artist to have input into the Director's creative process and see the results of that input visually through the live compositing was an ideal way to build confidence in the vision.

The overall benefits of Virtual Production for short films and music videos can be summed up in this quote from Jonathan, 'For me as a director, the amount of control I had to keep refining was fantastic, and it is a level of control I now expect to have going forward.'

Modularity

The modular nature of Virtual Production pipelines allow for specific pipelines and methods to be employed by a large variety of different productions, regardless of the size or scope.

Modularity in this scenario means that different areas of Virtual Production can be applied to different productions. An example is the difference between Project 1 and 2. Project 1 used a green screen, tracking system and live action actors to achieve the result. Project 2 however removed the green screen and live action elements and added MoCap actors.

Going forward I believe a valuable way of thinking about Virtual Production would be to break it into modular components. These components include:

- Tracking
- Green Screen
- Motion Capture/Performance Capture
- LED Wall/Volume
- Rendering/Real-Time

This provides benefits to potential productions looking to employ Virtual Production, as a flexible and modular pipeline can be created to fit the needs or limitations of a project. An example is Project 2. In Project 2 it would have been possible to shoot the entire short film using the same pipeline as Projects 1 and 3, but since Goodwin had access to the shoot location for free, the cost savings would be minimal. Traveling to the location does have a cost associated. Travelling with the crew twice (once for storyboarding purposes and once for shooting) would have made it more expensive, which provided the perfect opportunity to implement Virtual Production into the process.

06_Conclusion

Throughout the development of the three projects employing Virtual Production, I embarked on a journey of discovery and growth. Using the research question 'How can Virtual Production be used to create Flexible and Modular Pipelines for Short Film and Music Video Creation?' to guide me, I gained valuable insights into the challenges of integrating modern software and hardware into the creative processes of short film and music video creation.

After completing the creative works, I have reached the conclusion that Virtual Production can be used in the following scenarios for small-scale productions:

- Pre – Visualisation/Storyboarding
- In Camera VFX (Green Screen)
- Virtual Location Scouting
- Real Time Animation
- In Camera VFX (Volume/LED Wall)

The hardware and software has reached a point where it is now cost effective to complete a project using Virtual Production, which leaves the only barrier to widespread adoption being the lack of specific knowledge on how to set the pipeline up on the project by project basis[24].

This is the key finding of my research. Although there are multiple ways that Virtual Production can be employed to enhance the creative process, the common factor is the technical knowledge required to develop these pipelines. This is predominantly due to the fact that Virtual Production incorporates such a large range of different software and hardware components that are all required to work together in harmony in order to achieve a desirable experience for the creative.

Without the specific knowledge required to implement Virtual Production tools and techniques, small-scale productions are limited by two factors, the existing knowledge within the production team and resources available to research and develop their own workflows.

Thus far this has resulted in only the small-scale studios that have a background in research and development (like Corridor Digital[20]) being able to implement Virtual Production. Most small -scale productions simply do not have the existing knowledge and resources required to do this.

With access to the specific knowledge required, small scale productions will be able to implement bespoke modular Virtual Production components into their existing workflows, based on their needs and budgets.

Overall this will enable many more productions across Aotearoa and beyond to access the creative freedom, flexibility, enhanced collaboration, cost savings and more benefits that come with Virtual Production pipelines.

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