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THE FUTURE OF VIRTUAL BACKGROUNDS IN FILMMAKING

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ABSTRACT

This thesis undertakes a rigorous examination of the pivotal role played by *Virtual Production* (VP) and the integration of LED Projection Walls within contemporary filmmaking. VP, characterised as an innovative production methodology, signifies a dynamic departure from traditional film processes, affording unparalleled prospects for creative expression and effecting a transformative paradigm shift in the filmmaking workflow. The research conducts a nuanced exploration of the impact of VP on the cinematic landscape, accentuating its profound ramifications for creative autonomy, collaborative workflows, and the holistic filmmaking process.

The incorporation of LED Projection Walls, a consequential technological component fundamental to VP, epitomises a revolutionary stride in cinematography. These immersive and interactive tools empower filmmakers to dynamically visualise and adjust scenes in real-time, thereby nurturing a vibrant and iterative creative workflow. Through a meticulous analysis of technological progressions, this thesis evaluates how VP, combined with LED Projection Walls, facilitates the seamless creation of realistic virtual environments harmoniously intertwined with live-action elements. The study delves comprehensively into the challenges and opportunities inherent in the widespread adoption of VP and LED Projection Walls, addressing their transformative imprint on the film industry and forecasting their indicative future trajectories. The immersive capabilities inherent in LED Projection Walls contribute tangibly to an elevated plane of visual storytelling, providing filmmakers the latitude to craft intricate and realistic scenes with heightened flexibility and efficiency. As the film industry undergoes this profound technological metamorphosis, the research provocatively contemplates the future prospects and evolving terrain of filmmaking.

The fusion of VP and LED Projection Walls unfolds not merely as a response to contemporary narrative exigencies but also as a catalysing force for innovation, propelling the boundaries of creative expression within the cinematic medium. In essence, this thesis serves as an erudite exploration of the symbiotic relationship between Virtual Production, LED Projection Walls, and the evolving nature of filmmaking, furnishing insightful perspectives into their transformative potential and underscoring their paramount significance as integral components in the trajectory of cinematic innovation.

ABSTRAKT

Tato práce se zabývá důkladným zkoumáním klíčové role virtuální produkce (VP) a zapojení LED projekčních stěn v současné filmové tvorbě. VP, charakterizována jako inovativní natáčecí metoda, naznačuje dynamický odklon od tradičního způsobu natáčení, poskytuje jedinečnou vyhlídku na kreativní vyjádření a efektivní transformační změnu paradigmatu ve filmovém procesu. Výzkum se zaměřuje na podrobný průzkum dopadu VP na filmovou krajinu a vyzdvihuje její hluboké důsledky pro tvůrčí autonomii, společné workflow a holistický filmový proces.

Začlenění LED projekčních stěn, které jsou zásadní a základní technologickou součástí virtuální produkce, je znamením revolučního kroku v kinematografii. Tyto immersní a interaktivní prostředky umožní filmařům dynamicky vizualizovat a upravit scény v reálném čase, čímž podporují živý a iterační kreativní proces. Skrze pečlivou analýzu technologického pokroku, tato práce evaluuje jak virtuální produkce kombinovaná s LED projekčními stěnami, umožňuje plynulou tvorbu realistických virtuálních prostředí, které jsou harmonicky propojeny s živými elementy. Studie se komplexně věnuje výzvám a příležitostem spojenými s rozsáhlou adaptací VP a LED projekčních stěn, jejich transformačnímu dopadu na filmový průmysl a na předpokládanou předpověď jejich budoucího vývoje. Působivé funkce, které jsou s LED projekčními stěnami spojeny, výrazně přispívají k vyšší úrovni vizuálního vyprávění a poskytují filmařům svobodu tvořit realistické scény se zvýšenou flexibilitou a efektivitou. Jak prochází filmový průmysl touto technologickou metamorfózou, tak výzkum podněcuje k úvahám o budoucích vyhlídkách a vývoji tohoto filmového odvětví.

Spojení VP a LED projekčních stěn není jen odpovědí na současné vyprávěcí požadavky, ale jeví se jako katalyzátor pro inovaci, který posouvá hranice tvůrčího vyjádření v rámci filmového média. V podstatě, tato práce slouží jako erudované zkoumání symbiotického vztahu mezi virtuální produkcí, LED projekčními stěnami a vyvíjející se podstatou filmování. Poskytuje hluboký vhled na jejich transformační potenciál a zdůrazňuje jejich mimořádný význam jako nedílnou součást v procesu kinematografické inovace.

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ABSTRACT

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INTRODUCTION

Filmmaking is a medium of expression, a way of communication and storytelling, we try to visualise a story, striving to achieve the exact emotions and atmospheres that we can create based on what is accessible to us. Apart from the crucial importance of production, directing and acting, camera work, production design, sound design, costume, every department plays an integral role in bringing forth the vision to life in its purest form. During my course of study I have had the opportunity to collaborate and work with various creative individuals, under the impeccable guidance of our mentors from the department and the school, helping us understand the art of visual storytelling from the ground up. Exploring the ways we delve into the modern world of storytelling, with advanced technology but still keeping the conventional methods and tradition alive.

Examining the trajectory of film stock from its inception to its contemporary state reveals a consistent surge in demand and preference. The evolution is intricately intertwined with advancements in modern technology, transitioning from analog cameras to the ever-evolving realm of digital counterparts. The journey encompasses a shift from vintage lenses, imbuing texture and authenticity, to the integration of super-fast optics characterised by unparalleled precision. Furthermore, the transformation extends to the evolution of studio backgrounds over the years, culminating in the present ability to maximise the offerings of the new generation of virtual production. In this paradigm, the outcome of principal photography becomes a real-time, observable phenomenon. Inspecting further into the new possibilities of Virtual Production[1] (VP) and my interest which has always been engaged by films that require a lot of VFX[2]. These VFX heavy scenes influences the way the film is directed, photographed, designed and prepped for, how you light the scene, design the set locations and virtual elements are factors influencing the production of the project. In the conventional method it is a post-production heavy process, but with the current possibilities, it has so far proved to be more beneficial than problematic, conditions applied. To understand how much of a creative liberty it provides and how cost efficient the new era of virtual production is, I have done my research on *The Future of Virtual Backgrounds in Filmmaking*.

As honest as I can be, knowing there has been astronomical advancement in the field of virtual production in the recent decade, I was only truly enamoured by the technology used in *The*

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[1] Virtual Production - Virtual production refers to the use of digital technologies to enhance and streamline the various stages of filmmaking, from pre-production to post-production. It involves the integration of virtual and physical elements to create high-quality, immersive, and realistic visual content.

[2] VFX - Visual Effects

Mandalorian, where gaming software program Unreal Engine[3] by Epic Games[4] was used to create the possibility of real-time rendering of the footage with projected background and the use of In-Camera VFX[5] to avoid the limitation of perspective. At first, it was definitely the apparent use of Led Walls for projection of pre-recorded footage instead of green screen and compositing the recorded footage in post. Having only an intermediate experience with green screens, specifically based on that knowledge, I was intrigued about easier lighting options and methods which isn't to say the it becomes less creative and laborious but rather it only makes things more convenient and appealing. In combination with actual virtual environment where the certainty for getting the envisioned shot increases significantly, which inversely helps in seamless communication with the crew involved in the set. Naturally, upon some research and reading, I've had various more realisations about the significance of the roots from where it all started, the traditional method of virtual production is still being used with modern technology to even further the scope of creating a virtual reality and an environment. It is a true culmination of traditional methods and knowledge that has now transpired to become a universe of possibilities where filmmakers are not bound to any tangible restrictions which slows production, but instead the only limit is our imagination.

Advancing deeper into the ergonomics of the topic, I had questions which this thesis aspires to answer and hopefully be a guide for anyone wanting to explore the world of virtual production in filmmaking, an introductory journal with a personal understanding of what it meant in the past, what it means in the present and finally what it could mean in the future for an aspiring cinematographer like myself. The new era of Virtual Production has been made attainable with incredible advancement in with the help of already developing techniques combined with modern methods and is a revolutionary achievement in the field, but it wouldn't be fair not to credit the advancement in every other department involved in the process of creation, which now apart from the film industry also involves skilled professionals from the gaming sector.

The first chapter, introduces us to the conventional methods used for creating studio backgrounds, from paintings to projections. The films that first pioneered the technique, understanding its current significance and its influence in The Future of Virtual Backgrounds in filmmaking. Which leads us to the second chapter, where we further our knowledge, understanding the scope of virtual production with the use of VFX, (Green/Blue Screen compositing with *CGI[6]).* Although the industry is faced with huge benefits of adapting virtual production in combination with Led Wall projections, creating real-time environments, saving budget, the importance of the integration of conventional methods still plays a significant parts.

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[3] Unreal Engine - Unreal Engine is a widely used and powerful real-time 3D creation platform developed by Epic Games.

[4] Epic Games - Epic Games is an American video game and software developer, as well as a technology and digital entertainment company. Founded in 1991 by Tim Sweeney

[5] In-Camera VFX - Refers to visual effects that are created and captured during the actual filming of a scene, as opposed to being added in post-production through computer-generated imagery

[6] CGI - Computer Generated Images

The fact that the resources required to use the technology and the number of skilled professionals available at the moment is scarce, the cost to opt for this method would still be profoundly inaccessible for low budget films, and independent films. Hence, leading to the third and the final chapter where I state my assessment based on the research I have done, and answer the question I had raised in the beginning of the thesis research myself; ***The future of Virtual Production will continue its advancement in technology and software in years to come, but due to costly production process and even more costly skilled professionals and tech available at the moment, what category of filmmakers will be able to experience the transformational technology, and what could be expected of its future?***

Chapter 1: Once upon a time in Hollywood

1.1 History

Virtual backgrounds in filmmaking have an ever-evolving history that continues to grow more with the advancement in technology and structure day by day. Integrating the use of what was available and achievable at the moment when it first came into being, to see real-time reference of what it would finally look like during principal photography is where virtual production for filmmaking is at this moment. Examining early techniques such as painted backdrops, matte paintings, and miniatures, we explore how these methods paved the way for more advanced technologies, setting the stage for the integration of CGI and green screens. It explores the transition from traditional methods to the use of green screens, CGI, and the subsequent developments that have enabled filmmakers to create intricate and realistic virtual environments.

Backdrops; large painted backgrounds on muslin cloth that were used to create realistic or stylised environments for film and television productions, that did not need to be built. These backings were commonly employed to depict expansive landscapes, cityscapes, or specific settings that could be impractical or impossible to recreate on location. They have played a crucial role in enhancing visual storytelling. Although it helped set the atmosphere a little more, it was restricted to a static background which limited the cinematographers from creating a more realistic atmosphere, limited from trying anything in motion eventually leading to limited camera angles, and that led to the development of **Moving Backdrops;** the same large painted backgrounds were now a giant roller towel to depict moving scenery behind an automobile or a prop horse or a train for example. Although after techniques improved they projected motion picture film on a translucent screen which gave the illusion of a moving scenery. These backgrounds could be moved or panned to simulate motion in the background of a scene. This technique was used in the early days of cinema and was a precursor to more advanced visual effects methods.

As filmmakers sought more sophisticated and versatile methods for creating backgrounds, the transition from simple moving backdrops to more intricate Matte Paintings occurred. **Matte Paintings;** in the traditional sense, typically involve creating detailed backgrounds on a flat surface, often glass. These paintings were used in conjunction with live-action footage to create composite shots. The matte painting technique became more prominent as filmmakers sought ways to depict expansive landscapes or elaborate settings that were impractical or impossible to build physically. It's important to note that these techniques often coexisted and evolved concurrently, and filmmakers experimented with various visual effects methods to achieve the

desired results. As technology advanced, the use of matte paintings expanded, eventually incorporating more complex tools and digital technologies in modern filmmaking. Started with something basic like Front and Rear Projections. **Front and Rear Projections;** are cinematic techniques used to combine live-action footage with pre-recorded or pre-animated background images, creating the illusion that actors are in a different location or environment. Both methods have been historically important in filmmaking, though technological advancements have led to changes in their prevalence. It was widely used in the early and mid-20th century before the widespread adoption of digital technologies. They were popular for scenes involving driving sequences, outdoor landscapes, or large-scale environments.

With the advent of digital technologies, Front and Rear Projection techniques have become less common. Modern filmmakers often use green screens or blue screens combined with digital compositing to replace backgrounds during post-production. Digital replacement provided greater flexibility, control over lighting, and the ability to create entirely virtual environments. The use of **Green screens and Blue Screens;** in filmmaking, also known as chroma key compositing, began to gain prominence in the latter half of the 20th century. The choice of colour for the screen became crucial to minimise interference with the actors' costumes and skin tones. **Blue screens** initially became the more popular choice for chroma key compositing. Blue was chosen because it was less likely to match natural skin tones and was also easier to work with in terms of film emulsion characteristics. Over time, **Green Screens** started to gain popularity, partly due to advancements in film and digital camera technology. Green screens offered better colour separation from human skin tones and were preferred in situations where actors wore blue costumes. The advent of digital filmmaking and post-production in the late 20th century further facilitated the use of green and blue screens. Digital compositing tools allowed for more precise and flexible keying, making it easier to separate foreground and background elements. Today, both green and blue screens are widely used in filmmaking and television production. The choice between the two often depends on factors such as the actors' wardrobe, the lighting conditions, and the specific requirements of the scene.

While the use of green and blue screens allowed for more efficient integration of live-action footage with digital backgrounds, the true leap in CGI Technology occurred in the late 20th century, bringing about a revolution in visual effects and filmmaking. **Computer-generated imagery;** refers to the use of computer technology to create visual elements or entire scenes in films, television shows, video games, and other forms of media. CGI encompasses a wide range of techniques, including 2D and 3D computer graphics, animation, modelling, texturing, rendering, and compositing. Through CGI, artists and filmmakers can generate lifelike images, special effects, and virtual environments that may be difficult or impossible to achieve using traditional methods alone. It came after the widespread use of green and blue screen technology and marked a paradigm shift, enabling filmmakers to bring to life imaginative worlds, creatures, and visual effects that were previously unthinkable. As technology continues to advance, CGI continues to play a central role in pushing the boundaries of visual storytelling in the film industry.

The change in technique in the use of Virtual Backgrounds in filmmaking gradually evolved at a steady consistent pace starting from the late 19th century up until the early 20th century, but over time, as technology caught up, the advancements in the Virtual Production realm have been much faster. They have played a crucial role in enhancing storytelling, expanding creative possibilities, and addressing practical challenges, it has been driven by technological advancements and the industry's quest for more immersive and efficient filmmaking experiences. Throughout history, the film industry has continually pushed the boundaries of what is possible and has become an integral part of filmmaking, providing filmmakers with tools to create worlds limited only by imagination.

1.2 Method of Use

The possibilities of Virtual Backgrounds were expanding, but their use of it depended on the cost of production and the benefits it provided.

Painted Backdrops for filmmaking, also known as scenic backdrops or cycloramas, were traditionally crafted by skilled artists who specialised in scenic painting. The process involved careful planning, artistic talent, and attention to detail to create realistic or stylised environments. The process usually begins with discussions between the director, production designer, and the scenic artist to determine the specific requirements of the scene. Detailed sketches or concept art was created to visualise the intended backdrop. The backdrop was typically painted on a large canvas or fabric stretched onto a frame. Cotton or muslin[7] canvas was commonly used due to its durability and smooth texture. In some cases, a scenic artist could paint directly onto a wall or a cyclorama[8] (a curved background) built in the studio. The canvas or surface was prepared with a base coat, usually in a neutral colour. This provided a foundation for the subsequent layers of paint and helped create a smooth surface. The scenic artist sketched the main elements of the backdrop onto the canvas, blocking in the basic shapes and forms. This stage focused on creating the overall composition. Multiple layers of paint were applied to build up the colours and details. This could involve blending and layering different shades to create depth and texture. Fine details, such as architectural features, landscapes, or specific objects, were meticulously painted to achieve a realistic or stylised effect. Scenic artists often employed various faux-finishing techniques to mimic textures such as stone, wood, or fabric. Some backdrops incorporated sponging, stippling[9], or glazing to create visual interest and depth. After completing the painting, the backdrop needed sufficient time to dry thoroughly. The drying process could take several days. Once dry, the backdrop would be sealed with a clear protective coat to preserve the paint and enhance its durability. Painted backdrops, especially those used in large studio productions, were rolled for transport and carefully handled to avoid damage. Installation involved suspending the backdrop or

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[7] Muslin - Muslin is a cotton fabric of plain weave

[8] Cyclorama - A cloth stretched tight in an arc around the back of a stage set

[9] Stippling - The art or process of drawing, painting, or engraving using numerous small dots or specks

attaching it to a frame, depending on the specific needs of the production. The completed painted backdrop was then ready for use on set. It provided a realistic or stylised background for scenes, creating the illusion of a larger or different environment.

The cost of making painted backdrops in filmmaking varied widely based on several factors, including the size of the backdrop, the complexity of the design, the skill of the scenic artist, and the specific requirements of the film production. During the era when painted backdrops were more commonly used, such as the early to mid-20th century, the costs were influenced by both material expenses and the labor-intensive nature of the artistic process. Larger and more intricate backdrops required more materials and time to complete, leading to higher costs. Backdrops featuring detailed landscapes, architectural elements, or complex scenes demanded more artistic skill and labor. The level of detail and realism achieved by the artist could influence the perceived value of the backdrop. Larger studio productions with higher budgets would allocate more resources to create elaborate and realistic painted backdrops. If a production had tight deadlines, requiring the scenic artist to work quickly, the cost would increase due to overtime or expedited work. Installation expenses, including rigging and framing, were factors in the overall budget. Since making these backdrops was exclusively manual, it's important to note that creating painted backdrops was a skilled craft that required artistic talent, time, and resources, which contrary to current affairs, isn't the case.

Matte Paintings were a crucial technique in early filmmaking, allowing filmmakers to create realistic or fantastical backgrounds that would be impractical or impossible to build physically. The process of creating matte paintings involved several steps which were similar to **Painted Backdrops** that included planning, sketching, and meticulous painting. The process typically began with discussions between the director, production designer, and matte artist to determine the specific requirements of the scene. Detailed sketches or concept art was created to visualise the intended matte painting. Online painted backdrops and matte paintings were often created on large sheets of glass or other transparent surfaces. The choice of material depended on the desired effect and the specific needs of the production. The glass or transparent surface was prepared with a base coat to provide a foundation for the subsequent layers of paint. This base coat often served to create a neutral background. The matte artist would sketch the main elements of the scene onto the glass or surface, blocking in the basic shapes and forms. This stage focused on creating the overall composition. Multiple layers of paint were applied to build up the colours and details. The artist would paint fine details, such as landscapes, buildings, or specific objects, with meticulous attention to realism. The artists often employed various faux finishing techniques to mimic textures such as stone, wood, or sky. Techniques like sponging, stippling, or glazing were used to add depth and create realistic effects. The matte painting was created to blend seamlessly with live-action footage. Artists had to consider the lighting conditions and perspective to achieve a realistic integration. The matte painting was positioned in front of the camera, with the live-action elements filmed behind it.

The transparent areas of the painting allowed the live-action footage to be visible, creating the illusion of a larger or different environment. In post-production, the matte painting and live-action footage were combined using optical printing or compositing techniques.
Optical printers were used to combine different elements onto a single piece of film, creating the final composite shot. Additional adjustments or enhancements might be made during post-production to ensure seamless integration of the matte painting with the live-action elements.

Both matte paintings and painted backdrops involved skilled artists and required materials and resources, but the costs could vary based on *Size and Complexity, Materials, Artist Skill and Reputation, Production Scale, Time Constraints, Transportation and Installation, and Long-Term Use*. As technology advanced, the cost dynamics shifted. The advent of digital technologies and alternatives, such as green screens and CGI, impacted the demand and cost structure for traditional matte paintings and painted backdrops. They were labor-intensive crafts that required skilled artists and careful planning. The costs associated with creating them were justified by the artistry, craftsmanship, and visual impact they brought to film productions.

As filmmaking technology evolved, the industry gradually transitioned to more cost-effective and flexible alternatives, such as digital backgrounds and CGI, which have become more prevalent in modern productions. **Rear and Front projection** were techniques used in filmmaking to combine live-action footage with pre-recorded or pre-animated background images.

Rear Projection; A large, semi-translucent screen is set up on the film set. The screen allows light to pass through and serves as a surface for projecting the pre-recorded background. A film or slide projector is positioned behind the screen, projecting the pre-recorded background onto it. The projector needs to be carefully aligned to match the perspective and scale of the live-action scene. Actors perform in front of the screen while the projector casts the pre-recorded background onto the screen. The camera is positioned to capture both the live-action elements and the projected background. Lighting adjustments are crucial to ensure that the live-action elements and the projected background appear cohesive. This may involve adjusting the intensity and colour temperature of the lights on the set.

While the transfer from painted backdrops, matte paintings to front/rear projection did make the whole process less manual labor intensive and slightly more cost efficient, and the time required to make it decreased considerably, other factors similar to painted backdrops and matte paintings, like; Size and Complexity, Materials, Artist Skill and Reputation, Production Scale, Time Constraints, Transportation and Installation and Long-Term Use could have a higher production cost based on these varying factors.

Front Projection; A beam splitter, a partially reflective and partially transparent mirror, is placed at a 45-degree angle in front of the camera. The live-action scene is filmed through the transparent portion of the beam splitter, while a projector beams the background onto the reflective side. A

special screen, known as a retroreflective screen[10], is placed in front of the actors. This screen reflects light directly back towards its source. The projector is positioned behind the camera, projecting the pre-recorded background onto the retro-reflective screen. Actors perform in front of the retroreflective screen, and the camera captures both the live-action elements and the reflected background. The beam splitter ensures that the camera captures the live action without interference from the projected light. Similar to rear projection, lighting adjustments are crucial for achieving a realistic blend between the live-action elements and the projected background. With advancements in technology, traditional film projectors have been replaced by digital projectors.

Blue and Green Screens, also known as chroma key[11] screens, involve isolating a specific colour (blue or green) in the background and replacing it with a different image or video during post-production. A blue or green screen is set up as the background on the film set. The screen must be uniformly lit to ensure consistent colour saturation and avoid shadows or variations. Proper lighting is crucial to achieve a clean chroma key effect. Even consistent lighting on the screen helps to create a smooth and easily separable colour. Lighting on the actors and other elements in the foreground should also match the lighting conditions of the virtual background that will be added later. The actors perform their scenes in front of the blue or green screen. The goal is to capture the live-action elements while isolating the chosen colour in the background. During post-production, specialised software is used to perform colour keying, which is the process of isolating the blue or green colour in the background. The software removes the blue or green colour, leaving the selected elements (e.g., actors) with a transparent background. Once the chroma key process is completed, filmmakers can replace the removed colour with a virtual background or any other desired image or video.

The chosen background could be a digitally created environment, a filmed location, or any other visual element. Filmmakers may need to fine-tune the keying parameters to ensure a seamless integration between the live-action elements and the virtual background. This involves adjusting settings such as colour tolerance, spill suppression, and edge refinement to minimise artefacts and make the composite look natural. To enhance realism, filmmakers may add or adjust lighting effects on the composited elements to match the lighting conditions of the virtual background. Shadows and reflections may also be added to create a more convincing interaction between the live-action and virtual elements. The final composited shot is created, where the live-action elements seamlessly interact with the chosen virtual background. The result is a cohesive scene that appears as though the actors are in a different location or environment.

The integration of **CGI (Computer-Generated Imagery)** into green/blue screen footage which was soon introduced involves combining live-action footage, shot against a green or blue screen, with digitally created or enhanced elements during post-production. The initial phase involves shooting

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[10] Retroreflective Screen - Device or surface that reflects light back to its source with minimum scattering.

[11] Chroma Key - A digital technique by which a block of a particular colour (often blue or green) in a film or video image can be replaced by another colour or image

the live-action elements in front of a green or blue screen. In post-production, a process called chroma key compositing is used. This involves isolating the green or blue colour from the background (screen) and making it transparent. The transparent areas are then replaced with CGI elements. CGI artists create the digital elements that will be added to the scene. These elements can include virtual environments, creatures, characters, special effects, or any other digitally generated content. Match-moving, also known as motion tracking[12], is a crucial step. It involves tracking the movement of the camera during the live-action shoot. This information is used to ensure that the CGI elements are properly positioned and move realistically within the scene. CGI elements must be lit and shaded to match the lighting conditions of the live-action footage. This includes replicating the direction, intensity, and colour of the on-set lighting to create a seamless integration. Shadows and reflections may also be added to enhance realism and make the CGI elements appear grounded in the environment. The CGI elements are rendered, generating the final images or frames that will be composited with the live-action footage. Rendering involves calculating the lighting, shading, and textures to produce the realistic appearance of the CGI elements.

The live-action footage and CGI elements are combined in a compositing software. This involves layering the CGI elements on top of the green/blue screen footage. The transparency information obtained through chroma keying is used to blend the CGI and live-action elements seamlessly. Colour grading is applied to the entire composite to ensure visual consistency and enhance the overall look of the scene. Other post-processing effects, such as depth of field adjustments or motion blur, may be added for additional realism. Filmmakers and CGI artists review the composite to ensure that the integration is smooth and realistic. Adjustments may be made to address any issues, such as mismatched lighting or perspective. The final, fully composited shot is then rendered and prepared for inclusion in the final edit of the film or video.

The advent of Blue/Green Screen technology and CGI has had a profound impact on the cost and efficiency of virtual production in filmmaking. Traditional filmmaking often requires elaborate set constructions for various scenes. With blue/green screens and CGI, filmmakers can create virtual environments, reducing the need for extensive physical sets. This leads to cost savings in terms of materials, labor, and time required for building and dismantling sets. This flexibility reduces the need for extensive location scouting, travel expenses, and logistical challenges associated with shooting on location. This flexibility reduces the need for extensive location scouting, travel expenses, and logistical challenges associated with shooting on location. Virtual production enables quick and seamless changes in scenes and settings during post-production.

Filmmakers can easily replace backgrounds or modify environments without the need for reshooting. CGI can replace or enhance practical effects, reducing the costs associated with creating physical effects or animatronics. Filmmakers can achieve complex and realistic visual

[12] Motion Tracking - The process of recording the movement of objects or people

effects more cost-effectively through CGI, avoiding the need for expensive practical setups. CGI assets, such as virtual environments or digital characters, can be reused across multiple scenes or even different productions. This reusability enhances cost efficiency. While the upfront costs associated with implementing green/blue screen technology and CGI can be significant, the long-term cost savings and creative advantages often justify these investments.

1.3 Survey of the technological milestones

Painted Backdrops/Matte Paintings: During the Silent Film Era (Late 19th to Early 20th Century), filmmakers primarily used painted backdrops and practical sets to create different environments. At the time, it played a crucial role in filmmakers creating a more realistic atmosphere by adding these painted backdrops. It helped them expand their creative environment. It added to the visual aesthetics and involved a handcrafted charm delicately perfected by the craftsman, which influenced textures and intricate details. *Missions of California, a 1907 documentary by Norman Dawn*[13], was the first film to use a glass matte painting to augment the scenery. One of the most famous instances of a large-scale matte painting in cinema history is the work of artist Albert Whitlock for the film "The Birds," directed by Alfred Hitchcock in 1963. The film features a dramatic and iconic matte painting depicting the coastal town of Bodega Bay, California, where the story is set. Albert Whitlock's matte painting for "The Birds" is considered a masterpiece in the realm of visual effects. The painting seamlessly blended with live-action footage, creating an expansive and eerie backdrop for the film's suspenseful narrative. The matte painting was instrumental in conveying the menacing atmosphere of the film, especially during the bird attack sequences. While it's challenging to quantify which matte painting is the absolute largest, the work on "The Birds" is renowned for its size, impact, and the technical skill involved in its creation.

Painted backdrops and Matte paintings lacked the dynamic flexibility offered by digital alternatives. Once painted, changes to the backdrop were challenging, and filmmakers were limited to the specific scene depicted in the backdrop. Large, hand-painted backdrops can be cumbersome to transport and set up on a film set. The logistics of handling these backdrops can pose challenges, especially for location shoots. Outdoor shoots with painted backdrops are sensitive to weather conditions. Rain, wind, or extreme temperatures can damage or distort the painted surface, requiring careful protection and maintenance. The cost of skilled artists, quality materials, and the time-intensive process of creating painted backdrops can be relatively high compared to other modern techniques like green screens or digital backgrounds. While painted backdrops bring a classic and artistic quality to filmmaking, filmmakers today often weigh the benefits of these handcrafted elements against the convenience and flexibility offered by modern technologies.

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[13] Norman Dawn (25 May 1884 – 2 February 1975)- Was an early American film director. He made several improvements on the matte shot to apply it to motion picture, and was the first director to use rear projection in film production

Rear projection involves projecting background images onto a screen from behind the actors, providing a realistic backdrop for the scene. One of the early examples of rear projection can be seen in the film "The Power and the Glory" (1933), directed by William K. Howard[14]. It's important to note that while these films were pioneers in using front and rear projection techniques, the technology continued to evolve, becoming more refined and widely used in subsequent years across various films and genres. **Front projection** was initially developed and used in the 1950s, with one of the earliest notable instances occurring in the film "Forbidden Planet" (1956), directed by Fred M. Wilcox[15]. The film employed a technique known as "CinemaScope" and utilised front projection for several scenes. This technology allowed filmmakers to project background images onto a reflective screen, creating realistic and expansive environments for the characters. These projections helped add to the realism that the filmmakers were striving to achieve, it had controlled lighting, enhanced the practical effect, and had a consistent perspective. It allowed actors to interact with the projected background in real time, enhancing the natural flow of the scene. But like any other technique, this method also came with its cons which included limited flexibility of changing backgrounds during a shot. Once the footage is recorded, it's challenging to modify or replace the background. It required a controlled studio environment to manage lighting conditions effectively. This can be limiting for certain outdoor or dynamic scenes. Projections require additional space on the set for the projector and reflective screen, which may not always be feasible. While projections were an important innovation, it has become less prevalent with the rise of blue/ green screens and CGI.

The use of **Blue Screen** technology in filmmaking dates back to the early 20th century. One of the earliest known instances of blue screen compositing in cinema is in the film "Ben-Hur: A Tale of the Christ," directed by Fred Niblo[16] and released in 1925. Cinematographer A. Arnold Gillespie employed a technique that involved shooting actors against a blue screen and later combining the footage with miniature models and other elements during post-production. The use of **Green Screen** technology in filmmaking, also known as chroma key compositing, became more prevalent with the transition to colour filmmaking and advancements in visual effects. One of the early notable instances of green screen usage is in the film "The Thief of Bagdad," directed by Raoul Walsh[17] and released in 1940. "The Thief of Bagdad" utilised a variation of the blue screen technique for its special effects sequences. Although it wasn't a true green screen as we know it today, the principles of colour keying were employed in creating visual effects for the film.

The use of blue and green screens has become a staple in filmmaking due to the efficiency, versatility, and creative possibilities they offer to filmmakers and visual effects artists. The flexibility

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[14] William K. Howard (June 16, 1899 – February 21, 1954) - Was an American film director, writer, and producer

[15] Fred M. Wilcox (December 22, 1907 - September 23, 1964) - Was an American motion picture director. He worked for Metro-Goldwyn-Mayer for many years and is best remembered for directing *Lassie Come Home* (1943) and *Forbidden Planet* (1956).

[16] Fred Niblo (January 6, 1874 – November 11, 1948) - Was an American pioneer film actor, director and produce

[17] Raoul Walsh (March 11, 1887 – December 31, 1980) - Was an American film director, actor, founding member of the Academy of Motion Picture Arts and Sciences (AMPAS), and the brother of silent screen actor George Walsh.

in scene creation, cost and time efficiency, real-time interaction, consistent lighting, weather independence, creative freedom, special effects integration, and the reusability of sets have all amounted to the advantages of Blue/Green Screens. Having said that, they come with some drawbacks or challenges associated with their use, like spill and colour contamination, lighting complexity, reflections, and glossy surfaces can reflect the colour hence making it hard to key, actors may find it challenging to interact convincingly with physical elements that are not present on the set, this includes situations where characters need to touch or manipulate objects that will be added in post-production. Shooting dynamic camera movements or scenes with extensive actor movement against a blue/green screen can be challenging. This is because tracking and matching the virtual background with the live-action elements becomes more complex. Setting up a blue/green screen studio with proper lighting and equipment incurs upfront costs. This might be a barrier for smaller productions with limited budgets. Natural problems like weather conditions, and over-reliance on post-production can lead to a disconnect between the live-action elements and the virtual environment if not executed seamlessly.

The widespread adoption of green screen technology gained momentum in later decades, especially with the rise of digital filmmaking and computer-generated imagery (CGI). As technology advanced, green screens became the preferred choice due to the higher sensitivity of digital cameras to green colours and reduced issues with spill or colour contamination. The first movie to extensively use **Computer-Generated Imagery (CGI)** is often considered to be "Westworld," released in 1973 and directed by Michael Crichton. *Westworld* featured a sequence in which a robotic vision was created using early computer graphics. The CGI imagery was developed by computer graphics pioneer John Whitney Jr. and his company Information International Inc. Although the technology was in its infancy during that time, it marked a significant step in the integration of CGI into the cinematic landscape, paving the way for the development of CGI in the following decades.

The use of Computer-Generated Imagery (CGI) in filmmaking has become a standard practice, offering a wide range of advantages and creative possibilities. It provides unlimited creative freedom, it enables the creation of highly realistic and detailed visual effects that may be impractical or impossible to achieve with practical effects or traditional filmmaking techniques. Filmmakers can make adjustments to CGI elements during post-production, allowing for changes in lighting, colour grading, or even the entire scene without the need for reshooting. It provides consistency in visual elements across multiple shots and scenes and offers cost-effective alternatives to practical effects or elaborate set constructions. It may be more economical to create certain elements digitally, especially when dealing with complex or large-scale scenes, and allows filmmakers to create dynamic and ever-changing environments that react to the narrative or characters' actions, it is commonly used to enhance action sequences, enabling the creation of dynamic stunts, explosions, and visual effects that prioritise safety without compromising visual impact. It has been used successfully for aging or de-aging actors, providing a tool for filmmakers to tell stories spanning different periods without the need for multiple actors. CGI also allows

collaboration between artists and studios worldwide, leveraging the expertise of CGI specialists regardless of their physical location.

Advances in CGI technology have made it more accessible for smaller productions with limited budgets to incorporate high-quality visual effects into their films. There are also some challenges and drawbacks associated with its use including cost, as high-quality CGI can be expensive, especially for complex scenes or extensive visual effects. The costs involve hiring skilled CGI artists, software, and hardware expenses. It can be highly time-consuming as there is a crucial need for attention to detail. The over-reliance and the increased dependence on technology can lead to a loss of the tangible and realistic qualities associated with practical effects and CGI-heavy films may age quickly as technology evolves. It also poses a huge threat to achieving photorealistic CGI and technical errors in CGI, such as glitches, unnatural movements, or inconsistencies, can detract from the viewer's immersion in the film. While CGI has revolutionised filmmaking and enabled filmmakers to achieve visual feats previously thought impossible, its use requires careful consideration to balance its advantages with potential drawbacks.

1.4 Current Significance and Future Relevance

While the traditional Painted Backdrops/Backings have lost their significance due to the progress in technology, Matte Paintings are still used in filmmaking, although their usage has evolved with advancements in technology. While digital techniques such as CGI have become prevalent, matte paintings remain a valuable tool for creating certain visual effects and environments. Filmmakers often use matte paintings to enhance practical sets or extend the visual scope of a scene. By combining real-world elements with painted or digitally created backgrounds, filmmakers can achieve a seamless and visually captivating result. Matte paintings are particularly useful for period films or scenes set in historical settings. They are employed when filmmakers need to create fantastical or imaginary environments that are challenging or impossible to achieve practically. This can include otherworldly landscapes, alien worlds, or dreamlike settings. It can offer a cost-effective alternative to building elaborate physical sets or relying solely on CGI. This is especially relevant for smaller-budget productions or scenes that don't require extensive digital effects. While traditional matte paintings involve physically painting on glass or other surfaces, digital matte painting has become a standard practice. Artists create detailed digital paintings that are seamlessly integrated into the film through compositing. Digital technology has expanded the possibilities for creating intricate and realistic matte paintings that complement the overall cinematic experience.

The same applies to the use of Blue/Green Screen and CGI which is substantial, and their future relevance is likely to continue evolving. Blue/green screens and CGI are integral to the creation of visual effects in modern filmmaking. They enable filmmakers to seamlessly integrate actors and practical sets with virtual environments, creatures, or elements. CGI has facilitated the exploration of a wide range of film genres, from fantasy and science fiction to historical dramas. Blue/green

screens provide the backdrop for fantastical worlds, futuristic landscapes, and historically accurate settings. it is often used to enhance realism in scenes that would be challenging or impractical to film on location. Continued technological advancements in CGI tools, rendering capabilities, and real-time processing will likely open new possibilities for filmmakers. The integration of blue/green screens with virtual production techniques, such as LED[18] walls and real-time rendering, is likely to become more prevalent and the convergence of CGI with AR[19] and VR[20] technologies could lead to innovative storytelling experiences, both in filmmaking and in audience interactions with films. Artificial intelligence (AI) may play a role in generating certain visual effects, automating repetitive tasks, and enhancing the efficiency of CGI production pipelines. The combination of CGI with immersive technologies could lead to new forms of cinematic experiences, allowing audiences to engage with narratives in unprecedented ways.

[18] LED - A light-emitting diode (LED) is a semiconductor device that emits light when current flows through it.

[19] AR - Augmented Reality

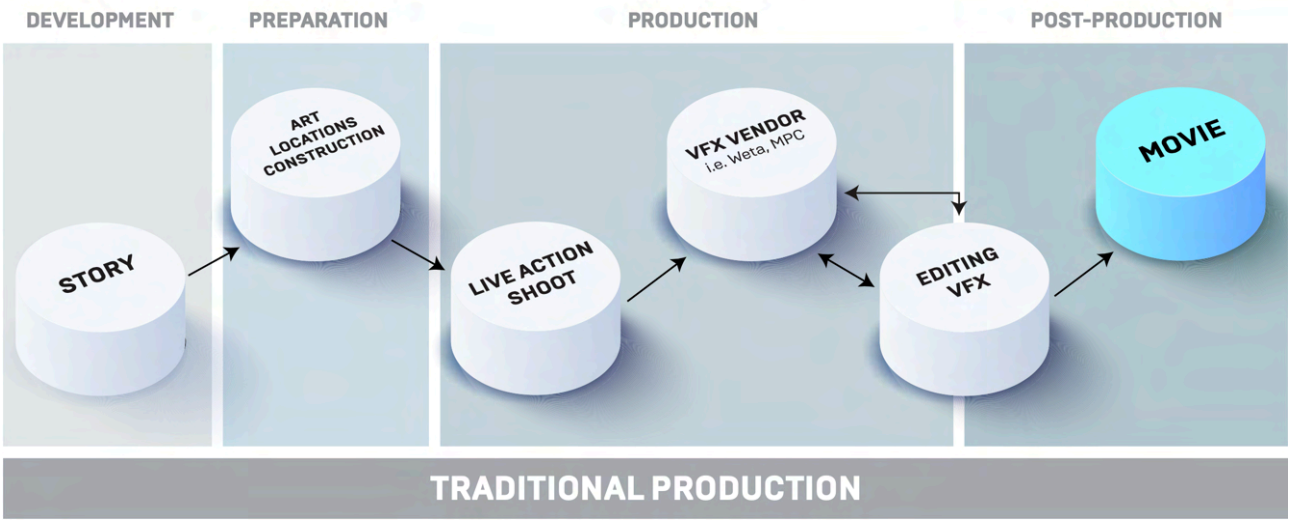
[20] VR - Virtual Reality

Chapter 2: Back to the Future

1.1 History

The cinematic landscape has been profoundly shaped and broadened by transformative technological strides spanning various eras. Notable milestones encompass the introduction of synchronised sound in film, the advent of colour negative stock, the refinement of optical compositing techniques, the attention afforded by motion control technology, the paradigm shift ushered in by digital compositing, the distinct realism facilitated by motion capture methodologies, and the immersive realms unlocked by virtual reality. Among these pivotal advancements, the query arises: does virtual production stand as another epochal game-changer in the ever-evolving realm of filmmaking?

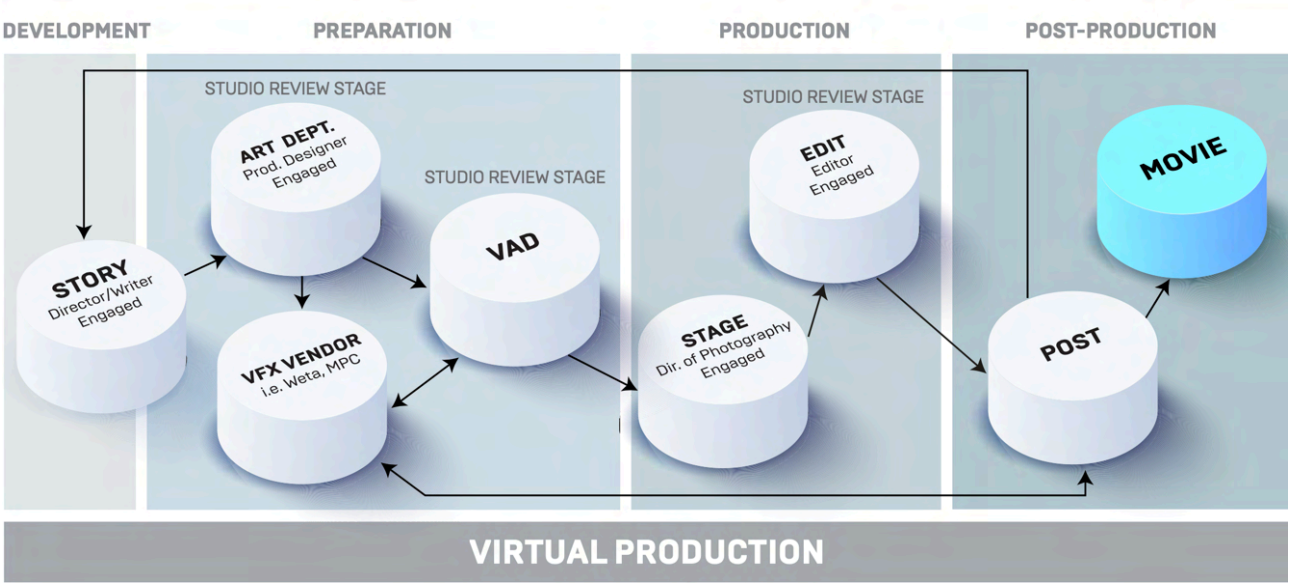
Virtual production constitutes a comprehensive category involving diverse computer-assisted techniques and visualisation methodologies within the realm of filmmaking. This approach integrates virtual and augmented reality with computer-generated imagery (CGI) and game-engine[21] technologies, providing production crews with the ability to witness the unfolding of scenes during composition and on-set capture. A substantial number of major films and television series incorporate some facet of virtual production, be it in pre-visualisation, techvis, or postvis applications. This study asserts that the potential of virtual production extends considerably beyond its current applications, advocating for its capacity to significantly enhance filmmaking. In contrast to conventional production methods, virtual production promotes a more iterative, nonlinear, and collaborative workflow. Leveraging real-time engines, this methodology allows for the immediate creation of high-quality imagery. Unlike traditional practices where different teams generate assets in isolation, virtual production fosters cross-compatibility, rendering assets usable across the entire filmmaking continuum, from pre-visualisation to the culmination of final outputs.



[21] Game Engine - A game engine is a software framework primarily designed for the development of video games and generally includes relevant libraries and support programs such as a level editor.

If we consider filmmaking like an assembly line, it is easy to understand that it is a straight line from start to finish, changing things during the process would be possible to make adjustments but at a higher cost. Iteration; a process of refining multiple successive attempts to reach the desired result, is a common procedure in the traditional method of virtual production. Although the confluence of green/blue screen and CGI has significantly transformed how we consume virtual production, it could fall a step behind against the present possibility of comparing the results with a creative feedback loop in real-time. When all the creatives involved have to take a guess at times or attempt things without knowing what it would result in has always in a way limited cinematographers, directors and actors alike to make the best use of their potential, amounting to an uncertainty which leaves them a little disconnected with the whole process itself. Having said that, taking the traditional form of pre-visualisation into account, there is room for improvement.

In stark contrast to conventional production methodologies, virtual production introduces a nonlinear and highly collaborative paradigm. This approach empowers department heads to collectively visualise intricate details in real-time, minimising the delay of critical decisions to post-production stages. Notably, the iterative process in contemporary virtual production commences at an earlier phase in the production timeline, enhanced by the utilisation of real-time engines and the immediate generation of high-quality imagery. Departing from individualised team efforts, virtual production fosters a more cohesive procedural framework wherein assets demonstrate cross-compatibility, seamlessly utilised from pre-visualisation through the conclusive final output.



The uncertainty which filmmakers usually come across while implementing the traditional production method is now very conveniently replaced with working imagery close to the final pixel, and the same high-quality imagery being produced with the help of real-time engine, iteration, experimentation have all been simplified making it cost efficient and agile. Apart from making the whole process more collaborative and inclusive, pre-production and principal photography has a

whole to avenue opened to them that can be achieved more organically, creative decisions regarding shots and scenes can be resolved much earlier in pre-production and isn't something left to be fixed in post. Virtual Production also alleviates the editorial process, providing imagery much closer to its final version. When a green screen image has to replaced by in-camera LED wall visual effects, the editor has much more options open to them, it makes editing sequences with heavy visual effects the same as editing sequences without visual effects. It enables editors to edit during principal photography and take shots that are required instead of making adjustments after principal photography or stumbling with issues later in post-production.

Virtual Production (VP) serves as a multifaceted solution, optimising efficiency and augmenting capabilities in both live-action production and postproduction visual effects.The distribution of virtual sets not only streamlines production timelines and expenditures but also holds the potential for heightened sustainability, reducing the carbon footprint associated with travel and transportation costs incurred in location filming. Rather than entertaining extensive travel for crews, equipment, actors, and sets, producers can strategically conceive and construct virtual locations within a computerised environment, subsequently realised on expansive LED screens referred to as The Volume[22].

[22] The Volume - It is the LED immersive soundstage, almost 360-degree stage of seamless LED panel screens and a ceiling, The Volume was first built at Manhattan Beach Studios in California for the first season of The Mandalorian

1.2 Method of Use

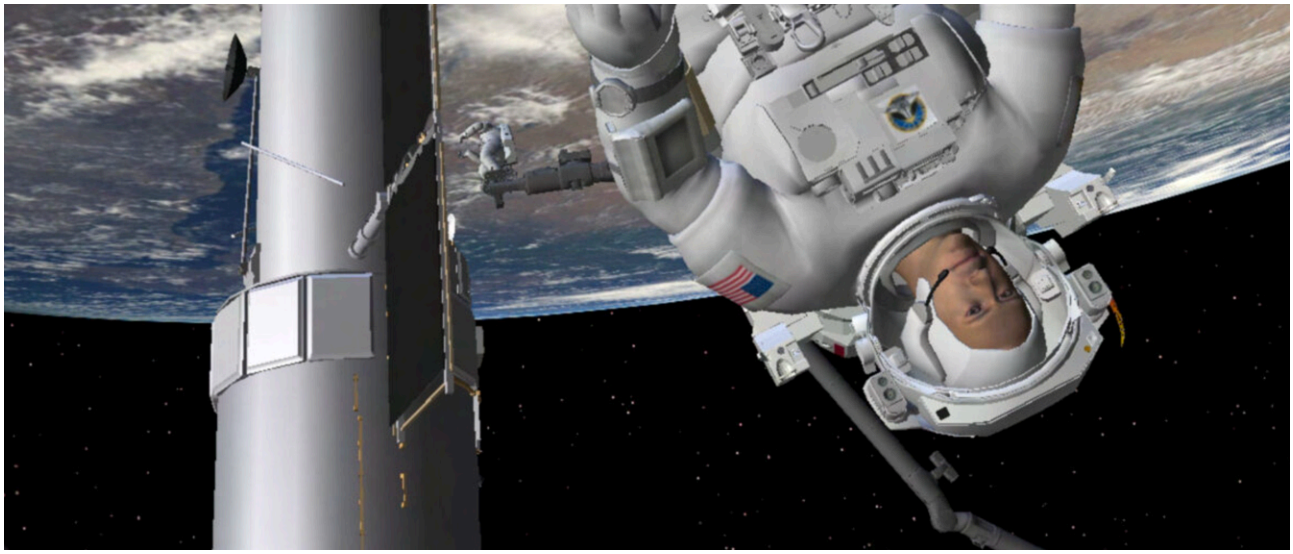
The efficiencies gained and the improved image quality resulting from virtual production engages a cascading impact, extending benefits to more constrained and time-sensitive productions. Through the strategic utilisation of virtual production techniques, facilitated by a real-time engine, network series, streaming productions, and independent films can attain a level of visual excellence and expansive scale traditionally associated with major productions. The incorporation of a real-time engine holds the transformative potential to alleviate budgetary constraints, schedule limitations, and developmental time bottlenecks that often impede smaller-scale productions, empowering them to generate imagery comparable to that of blockbuster counterparts.

Virtual Production (VP) constitutes a framework comprising an intricate array of techniques and technologies, divided into four principal domains: Visualisation, Motion Capture, Hybrid Virtual Production and Live LED Wall Virtual Production.

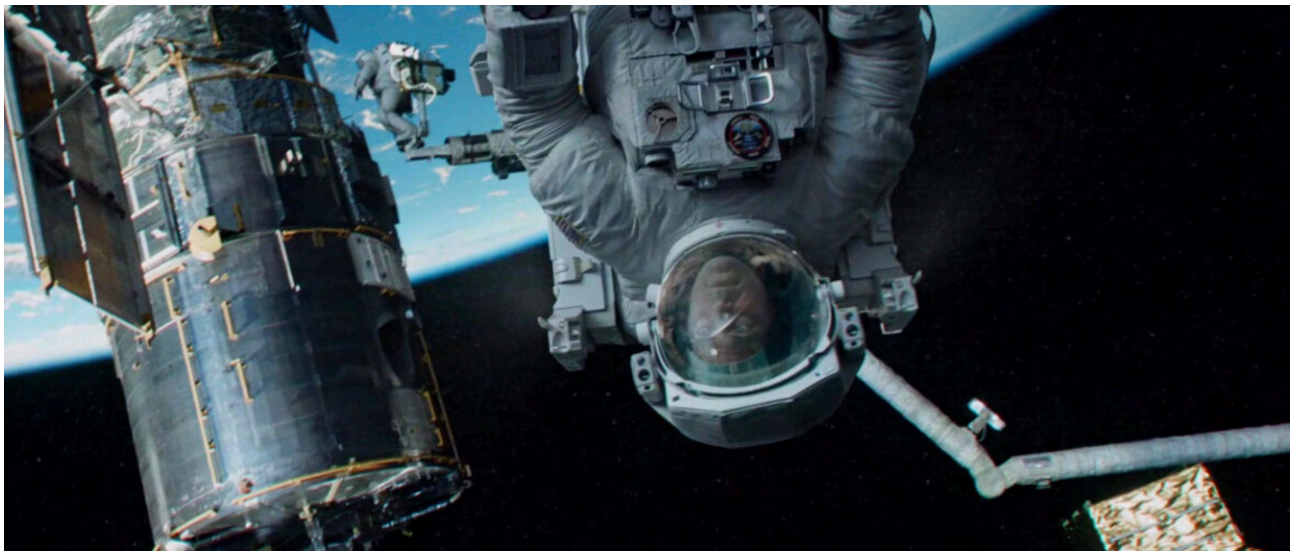
Visualisation; Within the context of virtual production, can be described as the prototype imagery designed to communicate the creative vision of a particular shot or sequence. This entails various manifestations, including pitchvis, previs, virtual scouting, techvis, stuntvis, and postvis, each serving distinct roles in the visualisation process.

Pitchvis, constitutes imagery crafted with the objective of securing project approval during its developmental phase, either by obtaining a green-light from a studio or influencing interest from potential investors. This visual representation may encompass specific signature sequences from the proposed project or an overarching trailer, strategically designed to articulate the filmmakers' creative vision. Some instances of successful project green-lighting attributed in part to the creation of pitchvis include prominent films such as Godzilla (2014), World War Z, and Oz: The Great and Powerful, amongst others.

Previs stands as a widely recognised and extensively utilised form within the domain of virtual production, frequently showcased in behind-the-scenes footage and visual effects presentations of prominent films. Previs involves the incorporation of music, sound effects, and dialogue to emulate the anticipated look and atmosphere of final sequences. This approach offers filmmakers a valuable advantage by facilitating experimentation with diverse staging and art direction elements, including lighting, camera positioning and movement, stage direction, and editing, all while avoiding the escalated costs associated with actual production. Previs finds its roots in preliminary techniques such as storyboards and animatics. Presently, the integration of previs has become a standard practice in major motion pictures, underscoring its ubiquity and significance in contemporary filmmaking processes.



*Previs of **Gravity***

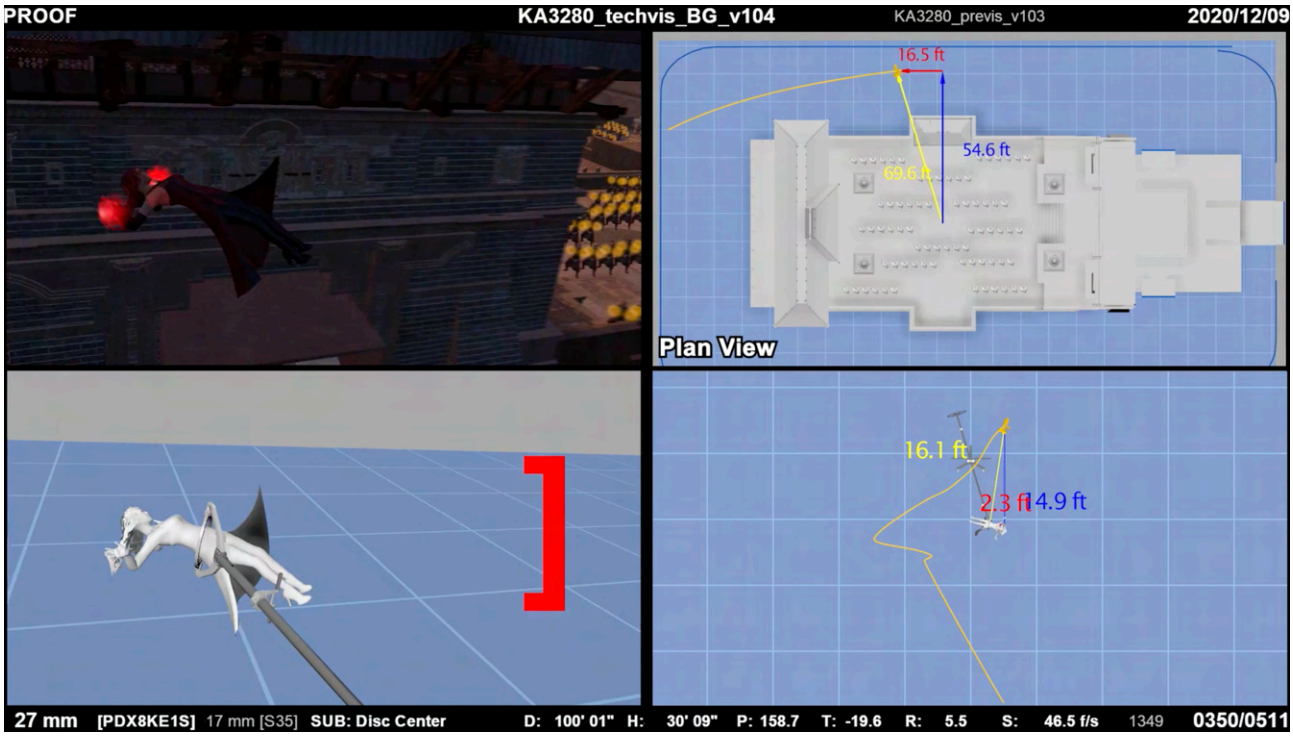


Matching image from the final production

Virtual Scouting refers to a completely digital version of a location or set that crew members can interact with, this can take place with the help of VR (virtual reality) headsets or on a computer screen. Of course the VR method includes reposition-able props and camera setups with different lenses which proves to be extremely beneficial for planing shots.

Techvis on the other hand refers to the combination of virtual components with real-world equipment to plan shots as well as combine already captured footage with virtual elements, a stage where camera movement, camera placement, lens choices can be confirmed reducing the risk of questionable virtual choices. Techvis, is primarily focused on the intricacies of physics and precise camera data, providing essential information for effects artists. In contrast to concerns related to visual fidelity or integration into an evolving edit, techvis prioritises the technical aspects

that contribute to the seamless execution of visual effects, ensuring a meticulous alignment with the physical parameters and camera specifications essential for the intended visual outcomes.



Techvis

Stuntvis like techvis is tailored specifically to choreographing the stunt work, usually assisted by a stunt coordinator or action choreographer, which include choreography, blocking scenes, testing the stunts, set design, rigging, weapon concept in collaboration with the director of photography, who works on the camera movement, lighting etc. Utilising the capabilities of real-time engines and their real-world physics simulations, stunt coordinators can directly transpose digital outcomes into tangible, physical manifestations. Its purpose is to convince directors and the producers on the vision, to test out few options before the shoot to make sure the camera movement works accurately and also provide all the different departments with a storyboard they can refer to for preparations.

Postvis involves making an image by merging live-action elements with temporary visual effects which helps conceptualise the vision better and guide post-production. This procedure comes in very clutch for directors and editors as it provides more visually developed scenes especially where visual effects pushes the story, it is a good tool to have to make communications easier with the VFX team.

Pre-recorded live-action footage : ***Captain America, The Winter Soldier***

Postvis : ***Captain America, The Winter Soldier***

Motion Capture; is the process of recording the actual movements of actors or objects and using that data to create digital models, actors have to wear suits covered in markers that are tracked by special cameras or a suit with built-in sensors.

Performance capture can be executed on conventional sets and it facilitates the integration of virtual characters into physical environments. Simulcam[23], a technique where a virtual camera synchronises with the movements of an actual camera in the tangible world, is frequently employed to overlay virtual characters onto live-action scenes in real time. This process serves to assist the production crew in refining framing and timing elements during filming.
Facial capture, a component of performance capture, is primarily dedicated to capturing the nuanced expressions and movements of an actor's face. This data serves the purpose of transferring the intricacies of their performance onto another character, be it human or non-human. While full-body animation commonly incorporates facial capture, there are instances where isolated facial capture is conducted independently of the broader body performance.
Full-body animation is essentially what the name describes, it replicates an actor's movement entirely onto a different character. It typically involves techniques such as scaling or retargeting, particularly when the animated characters have distinctive body geometry compared to the original actor. Examples of full-body animation includes works such as Avatar, the Gollum in The Lord of the Rings to name a few.

Hybrid Virtual Production; As the name suggests, hybrid virtual production is the use of camera tracking to composite green screen footage with CG elements. It is created as live preview and completed in post-production or is intended as final pixel in camera. Hybrid Virtual Production has been used for a while for live broadcast, but has also infiltrated into feature and episodic productions. There are two types of hybrid virtual production; **Real-time hybrid virtual production** which mostly first appeared in broadcast news, weather reports, where the person is chroma keyed live over a map with the forecast. The quality at that time was passable but over time the technology has since been improved to conclude with exceptional results, **and Post-produced hybrid virtual production** uses camera tracking data to create a live, in-camera composite image when shooting green screen. The live composite is usually at a proxy resolution and only used as reference or blocking shots while shooting infant of green screen. It helps the department heads understand the space and virtual elements better so the vfx in post are better integrated.

Live LED Wall Virtual Production (The Volume); Through decades of transformation and advancement, virtual production is at a point where image output from real-time engines can be projected on a live LED wall in combination with camera tracking to create final pixel imagery, solely in camera. As opposed to rear-projecting pre-rendered image, the use of real-time engine to create imagery for LED Wall projection, the image shifts in perspective, creating well synchronised parallax to the camera. LED wall projection is the culmination of all the previous efforts made in the realm of virtual production starting with rear projections in the 1930s, where it was commonly used for moving vehicle shots. The fundamental basis for this capability stems from the advancements in real-time game engines, exemplified by technologies such as Unreal Engine. These engines, renowned for their ability to render high-fidelity stylised or photorealistic real-time graphics, have

[23] Simulcam - The live compositing of virtual elements with live-action. Used for previewing virtual characters and environments during live-action cinematography. See also augmented reality.

evolved beyond their conventional application in final pixels for games or live broadcasts. Instead, they have become integral to the creation of animated content and are pervasive throughout every stage of the live-action film production process—from pre-production planning to on-set execution and post-production activities following principal photography.

When we talk about cost of production for the technology and resources being used in mainstream virtual production for filmmaking, banking heavily on the smart infrastructure of Unreal Engine in combination to the traditional methods, it has affected the cost within the industry in a much varied manner. While the benefits are proving to justify the expenses, the regular production costs vary depending on complexity and scale. Some of the following states the cost at which the advantages of virtual production are being taken by filmmakers but also to what extent is it available to the growing filmmaking community, both commercially and independently.

- **Cost Efficiency in Revisualisation:** The scope of previs significantly changes with the help of Unreal Engine, the revisualisation of scenes in real-time, at a fraction of the cost is something the extremely beneficial for the growing industry one would imagine. The need for making extravagant sets on extreme locations which is physically, environmentally, and economically exhausting, filmmakers can now explore different visual and narrative elements in a virtual environment, reducing the need for cost for all of those things previously mentioned.
- **Time Efficiency and Budget Control:** What this technology has empowered the creators is the ability to create atmospheres, that would take several days in creation if it had to be be made physically, but now since the possibility of virtual creation and the advantages of real-time rendering has only limited filmmaker to their imaginations. The possibility of being able to change scenes and set in a matter of seconds without having to worry about loss of natural light would affect the production significantly in every possible way.
- **Enhanced Productivity in Post-Production:** Like mentioned earlier, the opportunities that Unreal Engine's real-time rendering capabilities have opened up has accelerated post-production workflows. This seems to have affected the cost by reducing time invested or other resources utilised during the process.
- **Investment in Technology and Training:** Since the technology is only at its initial stage, there is a lot that is still the the beta version, where more possibilities and combinations are being tested to exemplify the benefits. Therefore the one of the costs the productions would have to expect is for training and R&D, to be able to maximise the freedom of creation.
- **Varied Impact Across Productions:** The cost is non-linear as the whole process of virtual production, it variedly depends on the scale of production, resources, and production types. Bigger shoots with more VFX demands and dependencies would cost differently than others that are not aligned similarly. Having said that, for smaller productions the whole cost would be mostly for setting up something that expensive and would depend on production and investments.

In summary, the adoption of Unreal Engine in filmmaking and virtual production has introduced both cost-saving opportunities and initial investments. The overall impact on costs depends on factors such as the scale of the production, the extent of visual effects needed, and the efficiency gains realised through the use of real-time technology.

1.3 Survey of the technological milestones

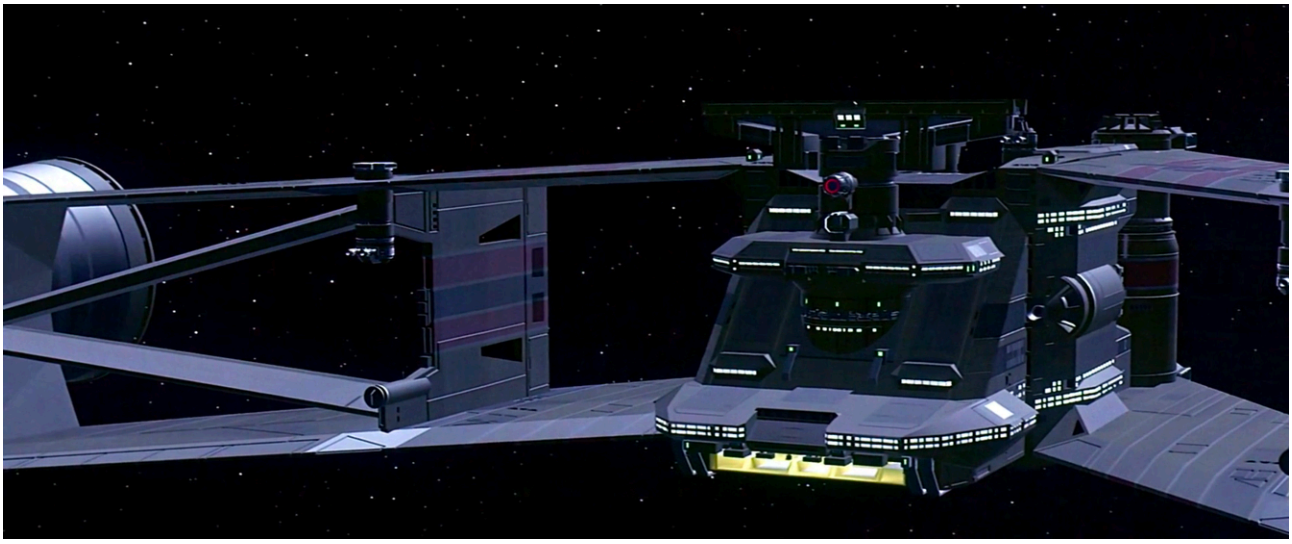
When we talk about using Virtual production and CGI in films it dates back to hundreds of films where some of the techniques first used were considered a revolutionary move in the step towards the future of filmmaking by the audience and the film industry alike. Being inspired by rear/front projections to set an atmosphere, to actors integrating with computer generated elements in real-time, the possibilities are in abundance and in an ever growing process of evolving. Here are some films that pioneered the technology at the moment and which paved way for future advancements.

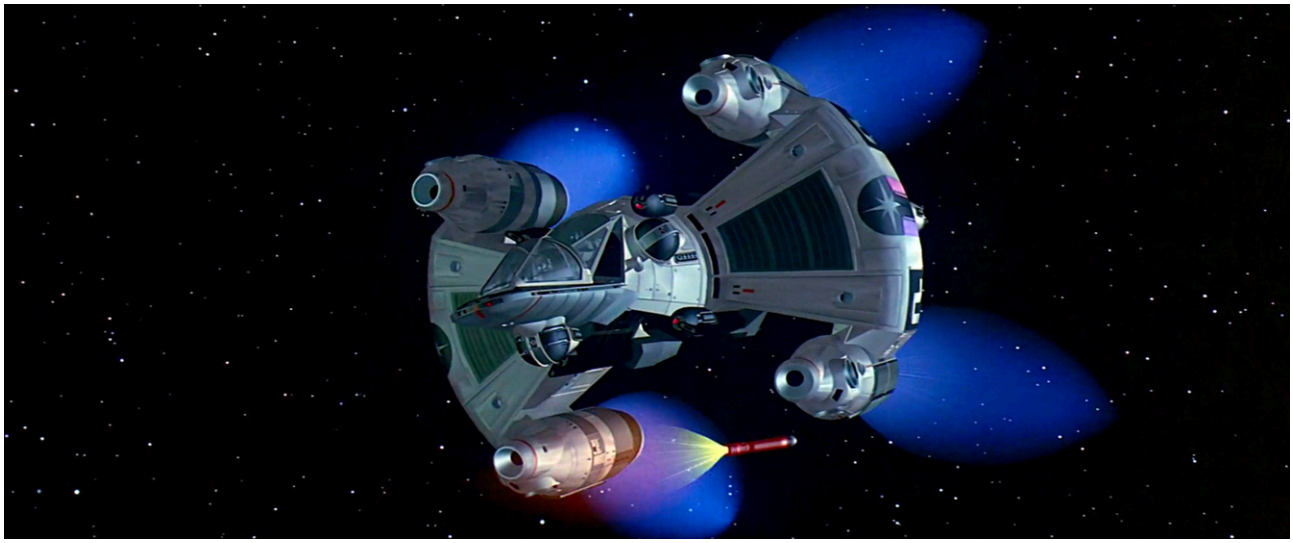
WESTWORLD 1973

Westworld was one of the fist films to use digitised footage for the POV of the robot played by Yul Brynner. Information International Inc. Los Angeles had developed a prototype image processing system which was suitable for what was required in Westworld.They developed programs instructing the computer to meticulously analyse each frame of production footage, converting visual data into numerical information. Subsequently, the computer synthesised this information to generate a novel image comprised of an array of squares. To ascertain the optimal resolution for their objectives, the production underwent multiple projection tests across various-sized theatres. Ultimately, it was determined that the most effective representation involved an image constructed from 3600 rectangles.

THE LAST STARFIGHTER 1984

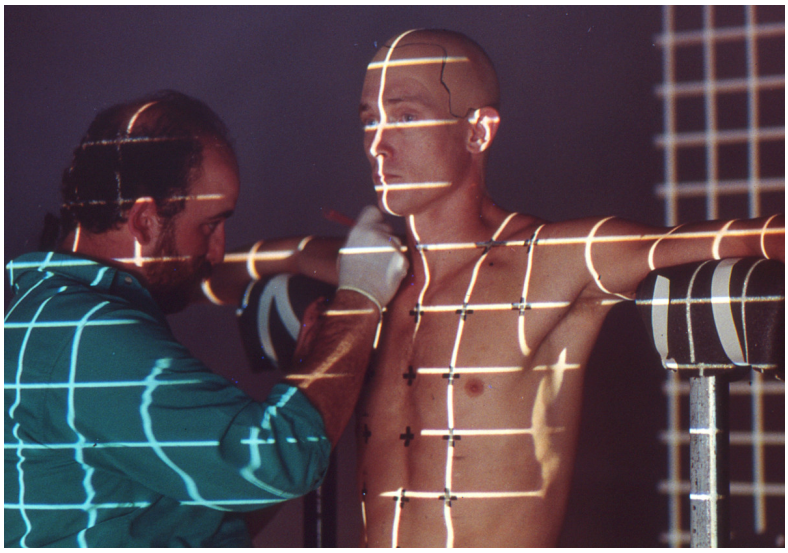
We’ve all known George Lucas’ Star Wars has been a prime example for the technology that was used for the film, it was revolutionary what was made possible in terms of virtual production at the time, but it was long before Star Wars, that other filmmakers were on the look out for better visual results. The 1984 space adventure The Last Starfighter, directed by Nick Castle, was the first film to actually replace all of its spaceships models with CGI, it was the first movie to use computer generated imagery to represent actual real life objects.



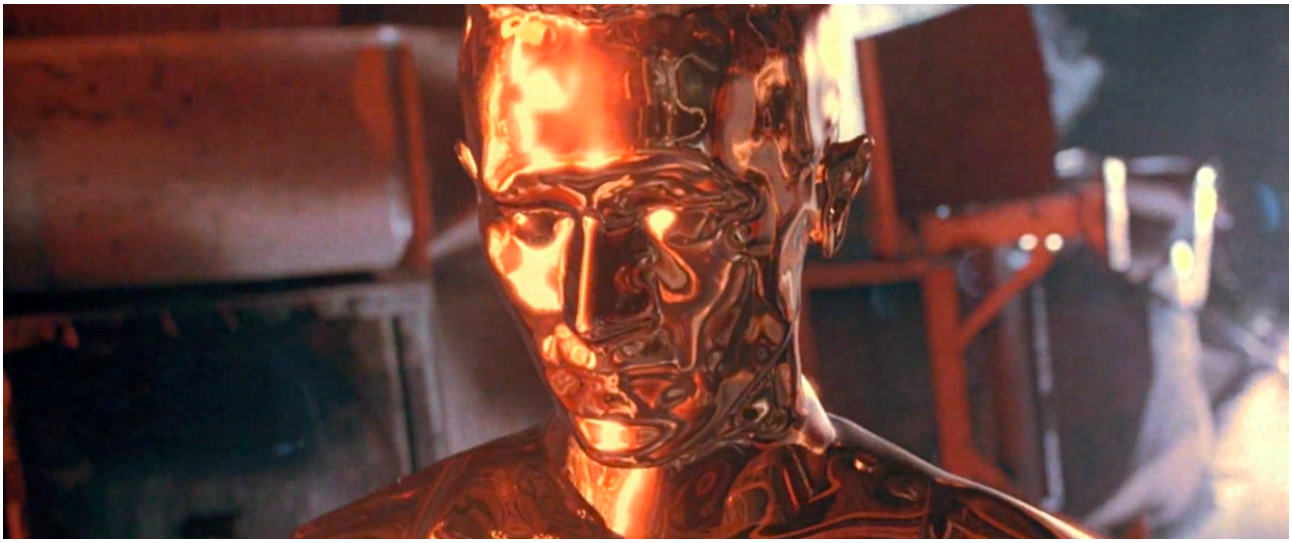


TERMINATOR 2: JUDGEMENT DAY 1991

James Cameron's biggest feat yet some might say, Terminator 2: Judgement Day 1991 was a huge example of how the limits of technology was pushed so we could all experience the catastrophic delight the film was. From advanced photorealistic morphing to advanced combination of live action and CGI, from advanced CGI liquid metal animation to advanced realistic human movements of CGI character, the film truly demonstrates the potential of virtual production



technology. The shooting schedule was front-loaded with effects shots to give the maximum time for CGI artists at Industrial Light and Magic to realise the liquid metal T-1000 (Robert Patrick). While traditional models and rear projections are used throughout the film, assistant VFX supervisor Mark Dippé noted "We were pushing the limits of everything – the amount of disc space we had, the amount of memory we had in the computers, the amount of CPUs we had. Each shot, even though it only lasted about five seconds on the screen, typically would take about eight weeks to complete."

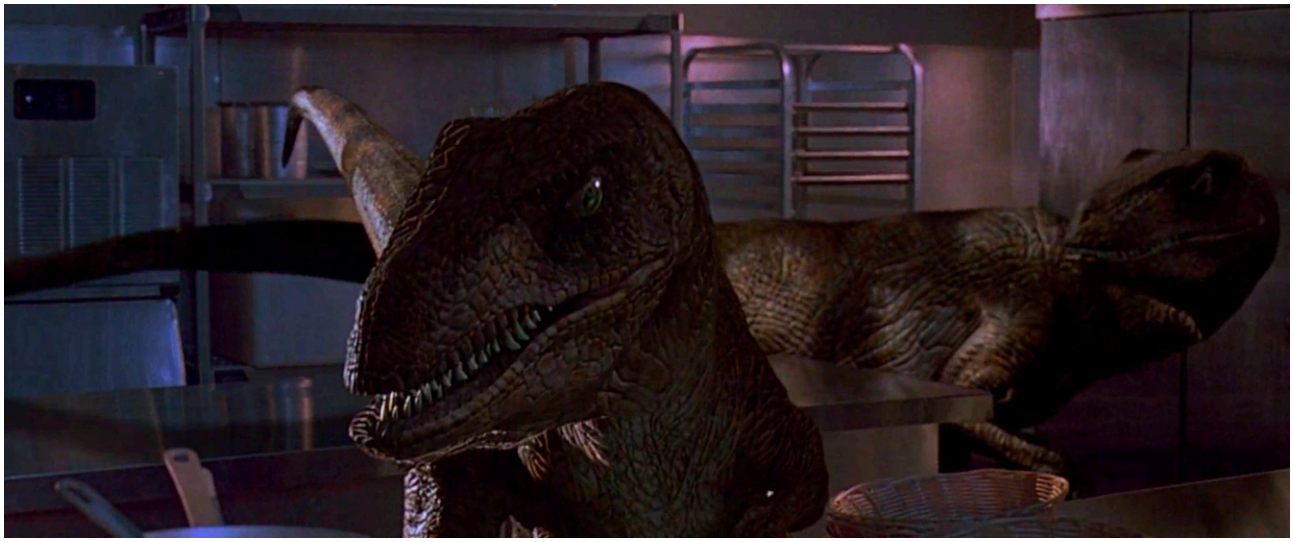


The team began by painting a 2x2” grid on a near-naked Patrick to shoot reference footage of him walking, before laser-scanning his head at the appropriately-named Cyberware Laboratory. Four separate computer models of the T-1000 were built on Silicon Graphics Iris 4Ds, from an amorphous blob to a fully-detailed chrome replica of Patrick, each with corresponding points in 3D space so that the custom software Model Interp could morph between them.

To create a more realistic chrome metallic shiny material for the robot, a shading program called the poly alloy shader, was developed which gave the T-1000 its chrome appearance, and ILM developed a new technology called “Make-sticky,” which allowed for textures applied to CG geometry to maintain their position despite having objects pass through them — such as the iron security gate in the psych ward where Sarah Connor was being held.

JURASSIC PARK 1993

Steven Spielberg stands out as a preeminent director with a well-earned reputation, attributable to his adept ability to captivate audiences and leverage diverse technologies in the creation of collaborative masterpieces, exemplified notably in the 1993 film Jurassic Park. Spielberg's ingenuity extended beyond his signature use of animatronics, as he seamlessly integrated state-of-the-art CGI into the production. Through the harmonious combination of these effects, the film achieved a remarkable level of photorealism, particularly evident in the awe-inspiring depiction of Brachiosaurs and Tyrannosaurus Rex, eliciting a profound and jaw-dropping impact on viewers.

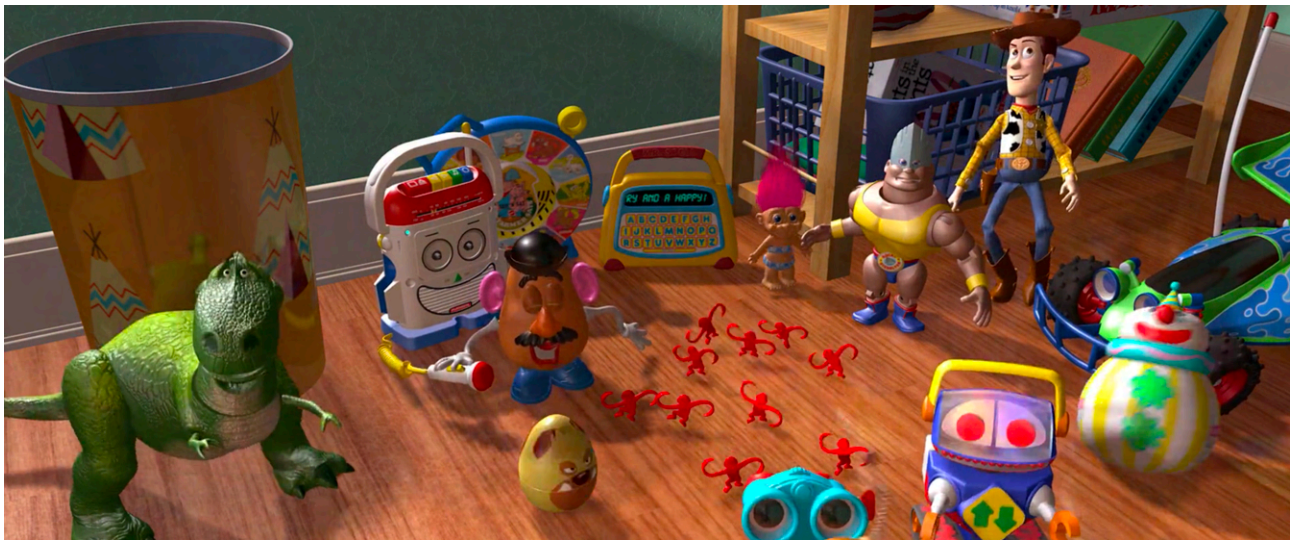


CASPER 1995

The family-oriented production, Casper, achieved a significant milestone as the inaugural Hollywood feature to introduce a fully computer-generated protagonist, predating the era dominated by Andy Serkis in this distinctive domain. Notably, it marked the forefront of cinematic innovation by pioneering the integration of computer-generated characters seamlessly interacting with live-action human actors—a groundbreaking concept that has since become a foundational element in the training and expectations of individuals aspiring to pursue careers in acting.

TOY STORY 1995

In the year 1995, shortly following the release of Casper, Pixar unveiled the inaugural feature-length animated film entirely crafted through computer-generated imagery (CGI). The groundbreaking success of Toy Story, featuring Tom Hanks in the charismatic role of Woody, not only propelled the film into a cultural phenomenon but also marked a transformative juncture in the cinematic landscape. This achievement ushered in a paradigm shift, with computer animation swiftly superseding the traditional practice of hand-drawn animation, establishing its reign as the predominant medium for children's movies in Hollywood.



THE MATRIX 1999

Similar to T2 in its impact, The Matrix, despite its incremental technical advancements, notably stands as the pioneering film to employ computer-generated (CG) interpolation in the creation of the widely adopted "bullet time" effect. Released in 1999, the film significantly influenced public perception of computerised special effects, marking a pivotal moment in the cinematic landscape. In the contemporary context, the trajectory of blockbuster filmmaking is often delineated as either pre-Matrix or post-Matrix, signifying a transformative shift wherein CGI has evolved from a Hollywood novelty to an indispensable component of twenty-first-century filmmaking.

LORD OF THE RINGS 2002,2003

Utilizing Weta Digital[24]'s Massive software, the inaugural instalment of the Middle Earth saga in 2001 featured a monumental battle sequence involving thousands of elves and orcs engaged in combat. Rather than relying on an extensive human cast to depict the armies, Peter Jackson opted for computer-generated imagery. In a departure from traditional animation methods requiring meticulous manual choreography of each soldier's movements, the innovative software endowed the digital extras with artificial intelligence, enabling them to autonomously engage in battle—a pioneering achievement in Hollywood. Which was followed by the creation of an exceptionally endearing and technologically sophisticated computer-generated creature named Gollum, this character marked a pivotal moment in cinematic history. Portrayed through the groundbreaking motion-capture performance by Andy Serkis[25], Gollum became the first photorealistic computer-generated character to be embraced seriously by movie audiences.

[24] Weta Digital - Wētā FX, formerly known as Weta Digital, is a New Zealand-based digital visual effects and animation company based in Miramar, Wellington

[25] Andy Serkis - **I**s an English actor and filmmaker. He is best known for his motion-capture roles comprising motion capture acting, animation and voice work for computer-generated characters such as Gollum in *The Lord of the Rings* film trilog

Notably, Serkis achieved the unprecedented feat of securing an various acting award without physically appearing on camera, symbolising the emergence of a new era in the realm of motion-capture acting.

AVATAR 2009

Avatar stands as the inaugural mainstream feature to seamlessly integrate both photorealistic[26] backgrounds and motion-captured characters, achieving an immersive adventure that deftly blurred the demarcation between live-action and animation while maintaining audience engagement. Furthermore, it served as a milestone for motion-capture actors and filmmakers by pioneering the utilisation of real-time animation, providing live feedback to showcase how the performances of motion-captured actors translated into the appearances of their virtual characters.

One of the formidable challenges confronting actors in contemporary filmmaking lies in the necessity to immerse themselves in their roles amid surroundings characterised by green walls, foam blocks denoting future obstacles, and individuals adorned with mocap[27] dots and suits adorned with ping-pong balls. This setting is further compounded by the reflective green surfaces that require meticulous lighting and colour correction. While advancements in technology have permitted cameras to offer a preliminary visualisation of the eventual film, facilitating the instantaneous substitution of computer-generated (CG) backgrounds and characters on monitors, this primarily aids in refining composition and camera movement. Nevertheless, it falls short of

[26] Photorealism - Is a genre of art that encompasses painting, drawing and other graphic media, in which an artist studies a photograph and then attempts to reproduce the image as realistically as possible in another medium.

[27] Mocap - Motion Capture

replicating the immersive quality inherent in practical sets and on-location shoots. Furthermore, due to constraints in rendering CG content, the freedom of camera movement is often curtailed, limited to predefined paths such as dolly tracks or a selection of pre-established shots for which content and lighting considerations have been meticulously prepared.

THE MANDALORIAN 2019- Present

The advancement witnessed in Stagecraft[28] and similar LED wall technologies transcends the mere generation of live, photorealistic 3D imagery by powerful Graphics Processing Units (GPUs). Notably, the distinguishing feature lies in the direct influence exerted by the movements and configurations of the camera on the 3D scene displayed. When the camera undergoes directional shifts, the image undergoes corresponding alterations, mimicking the dynamics of a real-world scene. This achievement, marked by its remarkable complexity, necessitates a real-time exchange of position and orientation data from the camera to a robust gaming PC, typically powered by the Unreal Engine. The intricate process involves the immediate translation and rendering of camera movements within the 3D environment, incorporating adjustments to perspective, lighting, distortion, depth of field, and other variables. The fast execution of these changes is paramount to ensure nearly instantaneous updates on the expansive LED wall. Any discernible lag between the camera movement and the corresponding background alterations, even by a few frames, would be perceptible to even the most unsophisticated viewer.

Unreal Engine

[28] Stagecraft - Is the process of producing or staging a piece of film or theatre. It is a technical aspect of the production that helps establish the overall look and feel of a set

Unreal Engine operated on four synchronised PCs to manage the pixels on the LED walls in real-time. Simultaneously, three Unreal operators had the ability to manipulate the virtual scene, lighting, and effects on the walls. The crew inside the LED volume could also remotely control the scene using an iPad, collaborating closely with the director and Director of Photography (DP). It allowed filmmakers to eliminate traditional location shoots, capture a significant number of intricate Visual Effects (VFX) shots with precise in-camera lighting and reflections, and collaboratively iterate on scenes in real-time while on set. The integration of Unreal Engine's real-time capabilities with immersive LED screens introduced a level of creative flexibility that was previously considered unimaginable. Changes to the story, visual elements, or other aspects can be implemented more efficiently, reducing the friction typically associated with traditional post-production processes.

The Mandalorian has set a groundbreaking standard in virtual production, opening up boundless possibilities. The enhanced flexibility of collaborative elements, particularly in pre-visualisation, facilitates easier modifications and rapid rendering, allowing for increased creative input during pre-production. A real-time engine supports a more iterative workflow by reducing friction in creating reference imagery.

Unreal Engine

The utilisation of a live LED wall instead of a static green screen provides additional benefits, such as heightened accuracy and control over framing and lighting. The prevalent challenge of shooting actors against vast green screens, leading to disorientation and frustration, is a familiar aspect of modern filmmaking. Virtual production emerges as a solution, offering a higher level of certainty over the final image and fostering greater collaboration with the art department, production designer, and visual effects team. These collaborative efforts significantly impact the final image,

with virtual production techniques providing a clearer understanding of shots and sequences, enabling efficient edits, and offering timely feedback during production.

The flexibility it allows for decoupling of story concerns from budgetary constraints, as making changes is more economical in virtual production shots than in more finalised visual effects. The seamless and flexible nature of real-time animation trends toward filmmaker-driven imagery with reduced reliance on engineering, resulting in final imagery closely aligned with the creative vision. In essence, virtual production fosters a more collaborative workflow, allowing various departments involved in a project to share assets and creative vision, departing from the more isolated and traditional workflows. The convergence of the virtual and real worlds in virtual production opens up a realm of possibilities, leading to a cinematic landscape where creativity encounters fewer obstacles.

Chapter 3: Everything Everywhere All at Once

1.1 Influence of Virtual Production in current times

The current state of the art in terms of Virtual production, is at an all time high, the incorporation of real-time engines have significantly changed the topography of Virtual Production as a whole. It emerges as a revolutionary influence in the realm of filmmaking, restructuring conventional methodologies and presenting unparalleled prospects for creative exploration. It empowers filmmakers with elevated creative authority throughout the filmmaking journey. The capacity to previsualize scenes in real-time facilitates dynamic adjustments to aspects like framing, lighting, and set design, cultivating a more iterative and collaborative approach to the creative process. This collaborative paradigm facilitates the seamless exchange of assets and creative visions, dismantling conventional silos entrenched in the filmmaking process.

In the virtual production world in recent past, The Mandalorian brought the world of LED wall projections and the utilisation of game engines for real-time rendering to the centre stage, and it doesn't mean it wasn't in the works before The Mandalorian, but it is extremely important to note that it isn't a single technology in the real of virtual production that is individually gaining momentum, but in fact it is the culmination of traditional methods all mixed and matched with modern technologies to get what is required for the production of the specific film. LED volumes for in-camera visual effects (ICVFX[29]) are presently considered a mature technology, while virtual production (VP) and extended reality (XR) have transitioned beyond the initial "hype phase" of development. The current focus is on refining system performance, making the technology more accessible to a broader user base.

The resources available at the moment is huge for a growing industry, since we see the significant growth of virtual production in films and other genres of production, the relevance of green/blue screen, rear/front projections are still very predominant. A lot of this consideration as to what technology should be used for the film is derived from the scale of the project and the intended use of computer generated images and virtual production. Now, due to the technology being at its peak which continues to evolve, it is with ease that filmmakers can produce anything with the help of virtual production, but as it has always been, the scope of being able to utilise this technology to its full potential depends on budget constraints and limited skilled professionals in the field. After Stagecraft built The Volume for the Mandalorian, there's been a justifiable rise in productions providing LED Wall setups for different kind of needs, needless to say ARRI and Sony have also already developed their own virtual production stage. Other production areas, like events, sports,

[29] ICVFX - In-Camera Special Effects

music videos and commercials might not be as intricate as making vfx heavy films therefore the rise of these LED Projection Walls that are on the rise.

Manufacturers are currently developing virtual production (VP) systems that are more user-friendly, with frequent software and firmware upgrades aimed at improving content production on LED volumes. While most LED displays adhere to the standard RGB format, emerging panels now integrate a fourth emitter of white LED. ROE[30], for instance, introduced a product called RGBW, claiming improved color accuracy and reduced post-production color correction needs. Another technology, presented by INFiLED[31] as 'Infinite Colours,' enhances various LED applications by offering full variations in tone, saturation, and color appearance in white light and custom colours. Furthermore, LED lighting manufacturers, such as Kinoflo with their MIMIK[32] tiles, are incorporating additional white bulbs alongside RGB. These tiles serve as a reflective surface and uniquely allow the playback of video content for realistic reflections, presenting a notable innovation in the field.

Starting from The Jungle Book and progressing to The Lion King (2019), the involvement of game engines in Virtual Production (VP) has seen a steady rise. In the latter film, the game engine has become an indispensable supporting system, overseeing the entire production's operations. This shift over the past decade has seen game engines gradually replace traditional computer-generated (CG) software, assuming a crucial role in rendering CG scenes and characters, production design, and scene scouting. Two primary factors drive this transformation: the film industry's escalating demands and advancements in the game industry.

From the film industry's perspective, there is a notable shift in the ratio of live-action scenes to Visual Effects (VFX) scenes in CG movies. Traditionally, CG movies focused primarily on producing live-action scenes, with VFX serving as an additional effect on green screens. Even highly advanced productions like Avatar maintained a significant proportion of live-action scenes. However, with the continuous advancement of CG technology, filmmakers now exhibit greater confidence in creating scripts that incorporate a higher volume of VFX scenes. Audiences, too, express enthusiasm for experiencing the visual excitement of VFX in cinema. Consequently, this trend has led to an increase in the proportion of virtual scenes in movies, often surpassing live-action scenes. The workflow of conventional Visual Effects (VFX) software operates in isolation and is insufficient for rendering extensive and intricate scenes. When a significant portion of a movie comprises virtual scenes, traditional software struggles to handle such a substantial workload. Conversely, the game industry has dedicated itself to enhancing user interaction experiences in virtual spaces over the past decade. Leading game companies have elevated the

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[30] ROE - ROE Visual, formerly known as Radiant, is an LED display manufacturer aiming to provide creative display for stage, architecture, TV studio, etc. Founded in 2006, ROE Visual has grown to be the top LED rental brand in the industry

[31] INFiLED - It is a high-tech enterprise specialised in developing and manufacturing large LED video equipment

[32] MIMIK - Is an image based video lighting tile that mirrors video content while applying a higher tonal and color rendering range. MIMIK delivers extended spectral bandwidth and cinematic color fidelity when lighting talent and set elements in virtual production environments.

quality of virtual scenes and characters to cinematic standards. The virtual engines they've developed are robust enough to consistently support the rendering of expansive Computer-Generated (CG) worlds, aligning perfectly with the requirements of virtual filmmaking.

Following the initial collaboration between game engines and movie production in The Jungle Book, game companies, notably Unity and Epic Games, have expedited the development of virtual filmmaking systems and tools. Their intention is to swiftly dominate an emerging market in Virtual Production (VP). This collaborative model is anticipated to be sustainable, continuously improving, and reshaping the structure of CG film production. As the degree of virtual production increases, the proportion of live-action scenes diminishes, marking a transformative shift in the dynamics of CG film production. Unreal Engine showcased the virtual photography tool utilised in Ready Player One during the 2018 Siggraph[33] event. Despite operating entirely within the game engine, this comprehensive set of tools encompasses nearly all essential cinematography elements. Parameters such as frame rate, resolution, light color temperature, shutter speed, and aperture value, typical of professional cinematography, can be finely adjusted within the tool. Additionally, the tool features an extensive array of virtual cinematography equipment, including tracks, Steadicam, drones, and cinematic lenses. All equipment parameters are integrated into the game engine based on real-world values. Numerous similar instances exist where both game and VR companies are dedicated to preserving the experience, skills, and culture inherent in classic filmmaking within the Virtual Production (VP) products and tools they develop.

The gradual enhancement of the collaboration between virtual filmmaking and traditional filmmaking culture signifies an extended and more profound exploration of the preceding trend. The increasing involvement of various filmmaking roles in Virtual Production (VP), as discussed earlier, brings forth their professional expertise and the ingrained cinematic culture derived from years of experience in the film industry. Some individuals may raise concerns that the emergence of VP has fundamentally altered the film industry, arguing that films created in Virtual Reality (VR) are no longer true cinematic productions but rather digital products. While it is undeniable that VP has transformed traditional filmmaking processes, this evolution is a response to the advancements in technology and the changing times. Nonetheless, sophisticated VR technology cannot entirely replace the enduring role and influence of traditional filmmaking culture.

[33] Siggraph - Is an annual conference centred around computer graphics organised by ACM, starting in 1974

1.2 Personal assessment of the research and Future of Virtual production

To predict the future of technology and its impact on filmmaking is inherently challenging. A plausible scenario for Virtual Production (VP) entails continuous enhancement and evolution of the computing hardware vital for its functionality. Specifically, the continuous advancement of CPUs and GPUs with each successive release is expected to elevate image fidelity further. Concurrently, the expanding adoption of virtual production is poised to generate increased opportunities across the filmmaking landscape. Virtual Production harbours significant untapped potential in the realms of aesthetics and the comprehension of storytelling, as asserted by creatives immersed in the field. This potential extends beyond the current applications of Virtual Production, which are primarily utilised as a green-screen proxy or a back-projection proxy. Essential to unleashing the potential of Virtual Production is the establishment of an environment that facilitates effective communication among departments, fostering a comprehensive understanding of the skills and technical parameters inherent in various tasks and creative processes. While Virtual Production is swiftly expanding its presence across diverse production domains, the absence of a complete feature film produced through this method is notable. Nevertheless, as an indicator of Virtual Production's extensive reach, it is noteworthy that every pivotal show currently incorporates immersive technology in some capacity.

It presents an opportunity for creative professionals to exert a more influential role at the project's inception, imprinting their artistic vision on the production's aesthetics. This ensures that early creative dialogues and decisions persist throughout the entire production cycle. Producers engaged in VP experience an elevated level of control over specific production aspects and planning. The integration of innovative VP techniques opens up creative possibilities, allowing practitioners to explore unconventional virtual camera movements and seamlessly merge Virtual Production cameras with physical cameras. Additionally, VP facilitates the experimentation of lighting, the execution of re-shoots and pickups through the Unreal game engine, and the utilisation of virtual sets as sources of lighting and colour. Beyond operational efficiencies, Virtual Production (VP) extends its impact to second-order business opportunities. One notable avenue is the creation of scans or models representing renowned locations or distinctive props, which can be licensed as digital assets to other productions. The capacity to recycle digital 3D assets and virtual scenes is poised to reshape the approach to budgeting and resource scheduling across productions. With the growing recognition of the business potential of VP, there seems to be a shift in the mindset of commercial producers, realising the dispensability of physical sets. This awareness stems from the perceived savings in both time and costs. For studio proprietors, the versatility of LED equipment and virtual sets enables their utilisation not only in commercial production but also in subsequent seasons of series-based projects, sequels, and other film-related content, further maximising the return on investment.

Virtual Production (VP) is anticipated to transition into the standard practice within the next three to four years due to its instantaneous visual coherence. The seamless interaction of lighting with

tangible, physically present objects contributes to a heightened level of believability, reaching 100%.

Having said that it is currently an extremely expensive way of shooting, which requires top notch technology, skills and resources to plan and prep for virtual Production. While we see different methods in the process of VP that could be helpful in different stages of pre-production, as package on the whole, it is something not all productions and filmmakers can have access to it at the moment. Establishing a studio equipped with a volume incurs a higher cost compared to traditional location shooting. However, as the number of Virtual Production stages infiltrates swiftly, coupled with a surging demand for content across various platforms, an opportune moment arises for entry-level runners, interns, and graduate trainees to acquire invaluable on-set experience in the field of VP. The existing scarcity of skills for Virtual Production necessitates a broadening of the employment search by companies.

The shifting dynamics of roles within the film production pipeline, coupled with the integration of skilled artists from the gaming sector, introduce novel creative and communication challenges. The film production process adheres to distinct methodologies, and the inclusion of individuals from the gaming industry poses a significant cultural challenge, influencing communication within the established on-set hierarchy. This cultural adaptation is a bilateral issue, impacting both the film industry's adjustment to gaming practices and vice versa. Individuals transitioning from the gaming sector perceive a Virtual Production shoot as a distinct aesthetic experience with a unique set of guidelines compared to their experiences in game development or other traditional film productions. Prominent logistical and technical challenges in Virtual Production involve the prohibitive costs, particularly for independent, low-budget television productions, and films. This cost barrier becomes apparent when contrasted with the relatively economical green screen techniques commonly employed in the industry.

In essence, the adoption of emerging technology, processes, and workflows boils down to the establishment of an efficient skills pipeline. In the present market scenario, characterised by a shortage of these specialised skills, companies engage in discussions surrounding an intense struggle for talent retention and express apprehensions about a potential 'brain drain.' This concern arises as technology companies actively recruit the most skilled professionals from the screen industries. As of now most skilled artists are coming from the gaming sector, the fact that gaming engines have been a part of the virtual production for filmmaking, the ecosystem will hinge on the investment in human capital rather than a mere investment in technology. With Augmented Reality also taking centre stage and with Artificial Intelligence on a significant rise, we can only imagine the endless possibilities for Virtual production. AI-driven software Cuebric enables filmmakers to dream up camera-ready media in seconds, for playback in a volume, imagine that in 5-10 years with all these brewing technologies that would’ve reached higher stage by then.

1.3 What can a cinematographer new to the ‘new phase of virtual production technology’ learn from it and how can they prepare for it?

In my personal experience, I can think of one instance where creating an atmosphere using the Led Wall Projection could be an interesting approach, beneficial and make the process easier. *Light Tonality,* an exercise headed by Prof. Klaus Fuxjäger, we experiment creating different atmospheres, in a studio setting and is shot on 35mm color film. I decided to create a moonlight, where I had to light and expose two characters of two different skin tones; caucasian and black skin tones. The complications or challenges that were faced during the production and were heightened slightly as it was being shot on film, which gave me on stock sensitivity of iso 500. Using that as an example and based on the things I would do differently, it intrigues me to think of the use of Led Wall Projection for the creation of the same atmosphere in a studio setting.

Rec 709. Kodak Vision 3 500T/7219

Graded

In the above example, although I don’t have the source of light in the frame, or the exterior, in theory should have been easier exposing the subjects, but where I went wrong was with my key light, a 10k HMI which was at a 10-15m distance, diagonally positioned at a height entering from the window, and 575s bounced on reflectors for general fill which now in retro-spect was too strong, a heavier diffusion synced with the right intensity would have made the moonlight atmosphere feel more realistic. As you can see in the graded version, even after bringing down the contrast and highlights, the ambience feels still too bright as opposed to a real moonlight where the shadows are subtle and diffused creating a play of light and dark across the surfaces.

Rec 709. Kodak Vision 3 500T/7219

Graded

The second example is where I would assume creating this exact scene with a moon outside the window, is something Virtual Production can come as a very handy tool, which in this example has completely failed to look like a real moon. There were a couple of issues with the moon, first it being too brightly lit where the details and the dark patches of the moon were overblown. It was being lit by a different light other than the key light which is the 10K HMI, the position of the moon might have been too close to the subject, and the light on it should have been more directional pointing directly at it, avoiding maximum spill on the background, a night sky. The closeness of the brightly lit moon also spills on the window glass which makes the whole exterior less believable as only being the moonlight. In the interiors on the other hand, the fill on the subjects turned out a little too much and the lack of highlights in the background made this seem more like spot light from the exteriors instead of the moonlight.

Of course, the possibility of creating something simple like this in a Led Wall Projection stage, would be fantastic right now if there were similar setups and projects already in progress, where a stage has been built and is ready to use after prior usage. But to built it up for a simple set up like that would not be cost efficient at all, in fact it might even be more time consuming and complicated for a simple use. Going the traditional method to create any atmosphere on a small scale would be more practical. Hoping the technology will be budget friendly and easily accessible in near the future, creating atmospheres like this would need a slightly different knowledge and skills of virtual production for directors of photography (DP) like any other member of the crew, it is a new learning curve. Due to the benefits of it in terms or production and cost, production houses are now organising courses for DPs and Directors alike along with other key members of the crew, to expose them to the possibilities for principal production banking on the knowledge of conventional methods.

The integration of LED walls into the realm of virtual production marks a transformative shift, presenting cinematographers with unprecedented lighting opportunities and creative liberty. This advancement enables cinematographers to leverage technology effectively in crafting images that seamlessly align with the narrative. Understanding the significance of lighting principles in both interactive LED settings and traditional cinematography, it becomes imperative for directors of photography engaging in this domain to acquaint themselves with the unique methods of illumination inherent to this innovative ambience. Specially shootings scenes with a reflective subjects or elements, having integrated Led wall lighting would save one a lot of time in post removing the green spill used in the traditional method.

Diverse categories of LED-wall systems exist, ranging from individual standalone configurations to comprehensive mixed-reality (XR[34]) stages equipped with a 3D-tracking volume, and various alterations in between. The engagement with these distinct setups necessitates tailored techniques, yielding contrasting outcomes. At the core of these systems is the utilisation of LED

[34] XR - Extended Reality

panels to showcase images, which has the ability to generate diverse levels of emissive lighting. Supplementary lighting on actors and tangible objects may come from sources such as LED ceilings or sidewalls, practical lights, and cinematic lighting apparatus. The strategic combination of these tools holds the potential to produce remarkably realistic outcomes. Within a standalone-style LED-screen setting, the content displayed on the principal screen can be synchronised with other LED screens positioned off-camera, providing supplementary reflections and interactive lighting effects. Furthermore, synchronisation with the system extends to "kinetic lighting" through the Digital Multiplex (DMX) network protocol, enabling the replication of lighting effects corresponding to the in-camera content.

An LED volume is composed of numerous individually addressable LED panels, offering precise control over each panel. Consequently, sections of the LED surfaces that fall outside the camera's view, including the ceiling, side walls, or any area not actively captured within the frustum area, can be manipulated to exhibit varying brightness levels or undergo specific alterations. This flexibility enables the creation of targeted reflection effects, such as those on vehicles or costumes.

The inherent softness of the screens' emissive lighting allows for the incorporation of actual movie lights, such as Fresnels, to replicate the intense illumination of the sun or other hard light sources. These lighting instruments are strategically positioned off-camera, either at ground level or suspended from the ceiling. In scenarios where lights are suspended from the ceiling, individual screen modules may need to be extracted from the volume to accommodate the overhead movie lighting. However, accessing and removing these panels may necessitate substantial grip work, contingent on the screen's specific access configuration.

This phase of Virtual Production at the moment is going to be a learning process, the demand for it although growing significantly, is still at its primary stage, as the technology is still quite new and evolving, there is a huge scope for an opportunity in Virtual Production world, given you have the interest and eye for it. The roles of every department head in the virtual production pipeline changes according to the requirement of the project which inversely depends on how VFX heavy the film is. Something to keep a tab on moving forward is the advancement in gaming engines that is transforming how we create alternate worlds, be it for video games, films, events or sports, the mutual utilisation of it in the years to come in said sectors is inevitable. Like filmmakers around that have so far adapted to every revolutionary advancement in the realm of filmmaking till date, we will continue to adapt and advance keeping the form of storytelling alive with everything the future holds, as long as the art remains pure and honest.

Conclusion

The cinematic domain has undergone a profound transformation with the inception and progression of Virtual Production (VP), compelling this research to undertake a comprehensive examination of its genesis, developmental trajectory, and consequential influence within the film industry. Through an intricate exploration of VP's conceptual underpinnings, technological nuances, and its transformative journey across various developmental stages, this study aims to provide a nuanced understanding of this innovative methodology that has redefined the conventional parameters of filmmaking.

At a macroscopic level, the scrutiny of VP's developmental trends throughout the current decade unveils a trajectory characterised by swift evolution and adaptive assimilation. The film industry, inherently responsive to technological advancements, has embraced VP as an influential instrument for both creative expression and enhanced production efficiency. This study meticulously delineates the overarching trajectory of VP in the film industry, illuminating its transformative potential and the diverse implications it introduces to the intricate tapestry of filmmaking processes. Such analysis extends valuable insights to filmmakers, industry professionals, and enthusiasts, delineating the present state of the industry and offering foresight into its potential future directions. The research duly acknowledges the inherent limitations precipitated by the scope of the study, consciously abstaining from delving into the microcosmic intricacies of VP technology. This methodical restraint aligns seamlessly with the study's overarching objective — to function as an introductory compendium and historical review of Virtual Filmmaking. By adopting a panoramic perspective, the research endeavours to inspire and fortify readers in search of a foundational comprehension of the VP industry.

The conspicuous absence of exhaustive technical details is compensated by a concentrated focus on overarching trends and impacts, providing a holistic panorama of VP's pivotal role in reshaping the cinematic panorama. Virtual Filmmaking, as elucidated through this research, constitutes a dynamic realm incessantly evolving to meet the exigencies of an ever-fluctuating industry landscape. The research postulates a future teeming with infinite possibilities, accentuating the continual refinement and evolution of VP concepts and technologies. The fluidity characterising the industry denotes that VP is not a static milestone but rather a dynamic force propelling innovation and creativity within film production. As technologies advance and visionary minds challenge boundaries, VP is poised to assume an even more consequential role in the annals of filmmaking. A salient insight derived from this research is the transformative impact VP has wielded upon the filmmaking process. The advent of real-time engines, exemplified in productions such as "The Mandalorian," has revolutionised the visualisation and execution of scenes. The capacity to previsualize scenes in real-time endows filmmakers with unprecedented creative autonomy, facilitating dynamic adjustments pertaining to framing, lighting, and set design. This iterative and collaborative paradigm has dismantled conventional silos inherent in the filmmaking pipeline, fostering a more coherent and interactive creative workflow.

Moreover, the research accentuates the collaborative essence of VP, illustrating its prowess in bridging gaps between disparate departments and divergent creative visions. The seamless exchange of assets and ideas has emerged as a hallmark of VP, enabling a more fluid and integrated approach to filmmaking. This collaborative paradigm not only amplifies creativity but also expedites the production timeline, contributing substantively to the overall efficiency of filmmaking processes. Looking forth, the research anticipates VP assuming a monumental status in the annals of film production. The industry's sustained exploration of VP concepts and technologies alludes to a trajectory where VP transcends its current status as an avant-garde filmmaking approach, progressively metamorphosing into a standard practice embraced by filmmakers across diverse genres and scales. As the technology matures and attains greater accessibility, VP is poised to transcend its current designation as merely an innovative approach to filmmaking, ultimately evolving into an established practice ingrained in the filmmaking ethos.

In summation, this research serves as a testament to the transformative prowess inherent in Virtual Production within the film industry. By furnishing a macroscopic analysis, historical retrospection, and glimpses into potential future developments, this study substantiates the ongoing discourse on the evolution of filmmaking methodologies. As the industry navigates the dynamic interplay of technology and creativity, Virtual Filmmaking emerges as a dynamic force, sculpting narratives and visualisations on the cinematic canvas. The trajectory of VP not only mirrors technological progression but also commemorates the boundless imagination and ingenuity of filmmakers who embrace this paradigm-shifting methodology.

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ANNEXES

ORIGINAL INTERVIEWS

Connie Kennedy, Producer *(War of the Worlds; The Adventures of Tintin; Star Wars: The Force Awakens; Thor: Ragnarok; Welcome to Marwen; and Avengers: Endgame)*

Watching virtual production evolve over the years, what do you see as some of its chief benefits to a producer?

I think one of the most important things is that they're going to get a volume of work that they probably wouldn't get otherwise because they would have to wait too long, and it would just be prohibitively expensive. Most directors that we have that come in, they've got a very experienced visual effects team. They're surrounding themselves with people who have a technical level of experience that they can rely on and that they trust.

That collaboration is crucial. You have to have great people on both sides, then you need an art department or what we call a virtual art department (VAD) that understands the virtual production process, so that they can build accordingly. And that takes a very specific type of skill. There are increasing numbers of people in both VFX companies and production companies that are working in collaboration with people doing large visual effects movies, where they can work together collaboratively with both the virtual and physical production.

What's the learning curve for filmmakers new to virtual production?

I think there's a couple of things going on when somebody comes in and it's a new process to them. We don't want to throw them into a situation where they're just in the frying pan and they're trying to figure it out. We want to come in, and first of all, do a lot of listening as to what it is they're trying to do.
And then we're going to talk to them about methodology and how to get there. The challenge is to try to not get in the way of what they already know how to do, which is to get the best performance out of their actors, and we need to facilitate that.

As long as a director understands that's what you're trying to do, it allows them to remain in charge and focused on the things that matter most to them and not be distracted with trying to figure out something that may or may not enhance what they're doing. In other words, they don't want to feel like they're handing off the final product. They want to feel like they're still in control of that. And so the trick
for us is to make sure that we are constantly serving them and their interests.
Jon Favreau, **Writer, Director, Producer, and Actor** *(Iron Man, Iron Man 2, The Jungle Book, and The Lion King and executive produced The Mandalorian)*

How do you prepare directors to work with the volume for the first time?

I made an arrangement with the studio for a lot of time for pre-production versus most television shows. I take the directors into a VR toolset very similar to what we used on The Lion King. We designed the sets together and looked at the artwork and storyboards together. Instead of rehearsals, they do a pre-production filming within the virtual world in VR with their crew.

After that, we have a cut that we can comment on. By the time they hit the real set, we've already gone through test runs, we've already made the show once together, and we've agreed upon a basic edit. They're prepared for it because they've already been there and shot it virtually. Then, we're there helping and trying to be good teachers and mentors. It makes it very exciting for us because we're not just making a show but we're making a new pipeline.

How challenging is the mindset of doing visual effects in camera versus deferring to post-production?

If you walk through Pixar or Disney Animation, you will see rooms and rooms of projects and teams of people working on films that are not yet being made. On the other hand, lots of live-action moments come out of random sets of circumstances that you capture in the moment. Animation is trying to develop spontaneity in post-production over months and years. I learned to leave room for both with Iron Man because a lot had to be planned well in advance to know what we were going to build and how it was going to be budgeted. But when Robert and Gwyneth were on the set, I ran it like an independent film and left room for improvisation and spontaneity. And so it's trying to strike that balance using the technology. Once you develop that environment, you stick people in a space that's digital because it's really right there. You may as well be in an independent film set. You can let them do whatever they want as long as they don't
go outside of what was planned. It's also having the nonlinear approach where you could always go back and pull a set back up and film some more. That's a safety net that you don't have in a normal live-action film, so it emboldens you to take greater chances.

Where do you see virtual production evolving?

As with any technology, the price point is going to come down and it's going to be easier to set LED volumes up. There's room for many different techniques but the story has to be the king. Oftentimes when something new comes around, people use it in ways that it's not optimised for. There's always been a dance between technology and storytelling. So as long as the filmmakers understand what it's good for and how to use it, it can be a very effective tool. That's part of what I'm really enjoying with The Mandalorian because as an executive producer, I get to work with a lot of new directors. We get to teach people how to use this tool and then we innovate off of what they

do with it. And they go off and use it for their own projects in other places. It's a natural and organic way for a new technology to proliferate.

Director of photography Greig Fraser, ASC *(Lion, The Mandalorian)*

What led your push into LED wall cinematography?

I suspect there's going to be more proponents of it once people get into the volume and get a chance to fully explore what it's good for. I think only a small portion of what we do as filmmakers is best served on a virtual stage. But when you do it right, it looks unbeatable and it gives the director a lot of opportunities they may not have ordinarily had in the normal film process.

Does it serve your purposes as a cinematographer to have everything ready on the shoot day versus deferring imagery to post?

It completely does. Typically, you get your cinematographer in for four weeks of prep, or on a big movie, it might be eight weeks of prep. Then you wave goodbye to the cinematographer and you say hello to all the visual effects people. This way, the cinematographer has much more say in what the lighting and framing are overall. So it's time well spent, and hopefully makes the backend easier and simpler.

How critical is colour science?

The perfect example is the desert. You put some sand on the ground for real. And then you've got sand beyond that. Those two colours have to be identical, otherwise you'll see the seam and it looks like a high school art project. It's a really fine balancing act of changing the color of the wall that you see and the color of the wall that you don't see, but it's creating the light on the ground. So, that's where the art comes from it and where our friends at ILM are very, very good at what they do.

Richard Bluff, In-Camera VFX, VFX Supervisor, ILM *(Doctor Strange, Lucy, The Avengers*)

How does the process compare to a more traditional visual effects pipeline?

Ultimately, what we execute is effectively the same—what's different is how we get there and which tools we use. One of the frustrating parts about working in traditional visual effects is dealing with post-production issues that are a result of not being able to visualise the CG work earlier in the process. If a DP is not able to frame up on a set extension, creature, or ship flying in during the shoot, and then you need to bend that plate to tell the appropriate story in post, it's not to

anybody's benefit. If they can't see it, then they can't frame or light for it without guessing. My career began in video games, building hundreds of environments for a PlayStation game. There was a budget for what that environment could be to ensure that it performed well for gameplay. It was a restriction, but by the same token, I think that the best kind of creativity comes from restrictions because you have to be thoughtful and intentional in your decisions. If you talk to anybody involved in the original Star Wars, they talk about being limited in how they could shoot. However, it was through all those limitations that the charm, the craft, and the creativity developed. It was the same thing for us as we were building environments for the screen. The conversation became: what is the most important thing, and what story are we trying to tell? Once we understood those points, the set extensions and environments would be optimised to serve the story rather than serving as a distraction.

Can you talk about the challenges of keeping assets performant for the screens?

We hit limitations every single day of production and left nothing on the table. You can assume that the scenes in hyperspace and regular space were the only environments where we had a lot of headroom left. One of the last things we shot in the volume on Season 1 was the Roost hangar from Episode 6. All the ideas we had through prep and shooting, and everything we were learning, came to a head with that environment. It was one of the most challenging and also one of the most successful environments on the volume.

The Roost was the size of a football field. Across three different days, we would shoot in three very different locations. We had crane arms, a vat of molten metal sparking and producing steam, and digital doubles walking around. Any one of those ideas could max out the memory footprint we had.

It required compromises, and the filmmakers had to become educated on what was possible. ILM did various benchmarking tests on the scene to see what would tip it over the edge. We would figure out where it was most important to feature some of these animated elements.

What are the limitations of working within an LED volume?

The lighting, because you can't currently use the LED panels to simulate the sun or get parallel light rays. So, whether it was Jon with his writing, Doug and Andrew with the environment design, or the DPs with their lighting, everybody crafted the scenes to support the lighting that we were comfortable we could reproduce. Also, the way that the camera focuses on LED screens is vitally important. You have to avoid the moiré pattern you get when focusing at just the right point on the screen. By the same token, the falloff we were able to achieve with the lenses chosen by Greig and Baz allowed the screens to fall off in focus most of the time, which helped with the illusion. It reminds me of when I first joined ILM back in 2003 in
the matte painting department. Back then, the majority of the movies we did were on film. Whenever I would create a matte painting to what I felt was like a 90 percent level, someone like John Knoll had the experience to say, "That's good enough." Just the transition of going from digital

to film provided that extra creaminess and the lines would be slightly blended, slightly softer, and with film grain. That, for me, was a eureka moment of a magic trick working by having the filming process take the work over the line.

Alex McDowell, RDI, Production Designer *(The terminal, Watchmen, Man os Steel)*

What was your initial experience with virtual production?

It began with Minority Report. The simple reason is that we started work without a screenplay. The movie didn't have a script for about 12 months, at least in a sense that they were ready to commit to it as a linear narrative. In many cases when there's not a script, the studio shuts the film down or keeps it in the writing phase, but Steven Spielberg was prepared to continue to fund an art department. With Minority Report, we had to build a world, and that meant defining all the holistic components that would make up the narrative before the narrative existed. We never know exactly where the camera's going to point so we are always in previs mode, and we are preemptively imagining how the director, cinematographer, and the actors are going to control, behave, and use the space that we're either building or finding as locations. We were defining world-building as an entire methodology for preemptively designing the cinematic space as a full world of options. In the case of Minority Report, that was Washington, DC in 2050. With a synopsis of about a page from Steven, we had to extrapolate the volumetric outcome of the architecture, the space, the journey, the choices, and all the way into technology. We developed the vehicles, all of the interfaces, how the environment moves. So, the full package. That was in previs, which evolved into what I would call "d-vis", which is design visualisation. I would make a solid definition between the idea of developing a global space in relation to the narrative intent. It's working with a set of rules defined by a film workflow combined with a world that was 40 or 50 years in the future. The rules end up being interpreters for that world and how all of the pieces interconnect. We continued to do that on Man of Steel. We developed all of Krypton, and then a slice of the narrative was taken from Krypton.

Did earlier methods of pre-baked previs present issues for your workflow?

My challenge as a designer is that in many instances, the previs comes from when the director is in writing mode. A lot of assumptions are made based on the script, but when it gets cemented into digital space, decisions are being made that bear no relation to the reality of the production. We've been presented with previs for a scene that would have cost millions of dollars to execute and only had thousands of dollars to make it real. So there's a big downside with previs unless it's informed by all of the moving parts. The most basic: how tall the walls need to be, but really what the possibilities are of moving a camera. Then really before that, a director making decisions based on what I would call a location, whether it's a set or it's an external location.

Either way, the director's standing in the space and making a decision based on what's there. How the director thinks and works in a real environment is not generally what they were allowed to do in a previs environment because they didn't connect. On the other hand, with Minority Report, there were sequences built by Steven Spielberg which were very specific to what Tom Cruise was doing and how he was connecting with a particular piece of the environment that he was engaged in. Our visualisation of the vertical highway is almost frame by frame a match to the final film because Spielberg is working within components that were already built by us: the size of the car, the way it moved, and how he's moving his camera through that space.

One thing that came out of Minority Report was a very close relationship with post-production and visual effects. As time goes on with films like The Jungle Book, there's very little differentiation made between pre-production and post-production. Previs and postvis, if done intelligently, are the same thing. If all of the decisions you're making tie together and reflect the intent of the film as a whole, then you make no differentiation between the virtual and the physical, or any combination of the two.

Have real-time tools enhanced your workflow?

Yes, absolutely. My earliest experience with real-time was with Habib Zargarpour, who designed a virtual camera tool. Not the first, but the most effective that I'd ever worked with, where we were working together and moving sets into digital space. The immediate impact for me was the necessity for real-time where you're actually in a fluid, proactive, constantly evolving design space, interacting with the camera and presenting the director with the constraints and opportunities. Then I got deeper into games and paying attention to game engines. I had a design company called 5D, and we worked in early development on The Jungle Book with Jon Favreau. We pitched the idea of virtual production in the sense of building it all in a game engine and creating all of the components in real time. Jon Favreau fully understood it, and they ultimately developed a fantastic system which became the default for smart studios.

Later, on Man of Steel, we set up parallel virtual environments for director Zack Snyder. He had a full system at home that matched the system we had in the art department. So we were taking him through sequences in VR and comparing notes in real time. The capability is so advanced and sophisticated and has such promise, sort of pervasively, that it is still shocking to me how conservative producers are in committing to that at the front of pre-production. There's still a lot of thinking about this as post-production. There needs to be a willingness to completely embed and be prepared to commit to a fully digital workflow with shared assets from the beginning to the end of the production, pre-production to post.

The more this happens, the more you create efficiencies that are solved in pre-production. That means that what you shoot is predetermined as being more efficient and cost-effective to do in camera, and which shots are better suited to post. There's a fully holistic production capability

that’s sitting there. We use real-time on every single tiny element that we do in my design studio. Our whole team understands it, whether they’re architects, engineers, illustrators, developers, or graphic designers. It’s become pervasively available.