HASSS
Humanities, Arts and Social Sciences Studies

Review Article

Humanities, Arts and Social Sciences Studies
https://so02.tci-thaijo.org/index.php/hasss
ISSN (Online): 2630-0079

VIRTUAL PRODUCTION: INTERACTIVE AND REAL-TIME TECHNOLOGY FOR FILMMAKERS

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Received: *29 November 2021*
Revised: *3 November 2022*
Accepted: *4 November 2022*
Published: *16 January 2023*

Citation:
Chanpun, P. (2023). Virtual production: Interactive and real-time technology for filmmakers. Humanities, Arts and Social Sciences Studies 23(1): 9–17.

ABSTRACT

Over the last decade, virtual production technology has been used in several high-end films, television, and video game productions. Virtual motion pictures and three-dimensional animated previsualization are transforming the film and television industries, and virtual production is increasingly being used in the film industry, visual effects, and game studios. With the technology, filmmakers and their teams can create higher-quality material more quickly and affordably and can now plan and create films in real-time. As a result, individuals may help conceptualise and convey their creative ideas more effectively during the early stages of the filmmaking process. The traditional script-to-screen method is being abandoned for quick iteration and instant feedback, and this novel technology also enables real-time visual interaction between users and a virtual environment. As virtual elements gradually supplant actual props in filmmaking, users can now interact with virtual set extensions and live-action footage. Although this technology has grown in popularity, little has been done to document the various ways of incorporating it into production. This study investigates the components of virtual production to describe the relationship between traditional computer-generated imagery (CGI) and the filmmaking process, the use of the virtual production technique to reduce the limitations of filmmaking, the components of virtual production technology, current advances in virtual production filmmaking and the advantages and disadvantages of virtual technologies; it also identifies distinctions between virtual and traditional filmmaking processes, all to improve the understanding of possible techniques for assisting producers and directors in shifting to this new filmmaking method. The conclusion of this review will show the characteristics of virtual production and its impact on the film industry and demonstrate the relevance and rationality of virtual technologies used today and in the future.

Keywords: Animation; film; virtual production; virtual filmmaking; real-time

1. INTRODUCTION

Since the 1990s, real-time computer graphics have advanced significantly in narrative filmmaking. Virtual production is a new filmmaking technique that creates narrative films using real-time 3D computer graphics (Kuchelmeister, 2020). Indie filmmakers can take on the roles of director, cinematographer, editor, and animator. Production studios already use virtual filming in film, visual effects, and gaming. The technology enables unprecedented pipeline flexibility and, more importantly, represents a shift in the way films are produced and collaborated on. While this is especially true for computer-generated imagery (CGI), the technology also significantly impacts how live-action films are made and fundamentally alters the pre-production process, which in turn accelerates the feedback and iteration processes associated with the traditional screenplay-to-final-film production process.

In the last decade, advances in real-time rendering and game engine technology have enabled the creation of virtual worlds as detailed as a typical visual effects pipeline. Along with performance capture, new technologies such as volumetric capture, real-time Raytracing, and image processing powered by artificial intelligence are rapidly becoming available (Kuchelmeister, 2020). Game engines fuel this revolution, which is the point at which traditional filmmaking concepts collide with contemporary reality. For filmmakers, game engines are free, simplified, and customisable tools. Virtual production enables filmmakers to interact in real-time with a 3D virtual world, just as they would with a live-action production. The interaction could be anything from a straightforward pitch visualisation tool to a photorealistic multiplayer game with the objective of "creating a movie" and everything in between (Patel, 2009). As with most aspects of filmmaking, there is no upper limit to cost or complication. Apart from technological obstacles, new capabilities, resources, channels of communication, and asset creation are required.

Virtual production is a relatively new trend in filmmaking that has been incorporated into feature films, television, video games, and live performances. Despite the rapid growth of this new filmmaking style and easier access to the necessary equipment, little has been written about the numerous options for integrating it into a production pipeline (Bennett and Carter, 2014). This study delves into the components of virtual production, outlining its relationship between traditional computer-generated imagery (CGI) and the filmmaking process, virtual production techniques to reduce the limitations of filmmaking, components of virtual production technology, its advantages, and some distinctions between virtual and traditional film production methods. The emphasis will be on educating filmmakers and artists about emerging technology.

2. VIRTUAL PRODUCTION FOR FILMMAKING

Film production has been in the early stages of adopting virtual production techniques and technologies to aid filmmaking. To fully understand the relationship between virtual production and the present filmmaking process, this review will explain it in three sections which are defined as case studies. They explore:

1. The relationship between traditional computer-generated imagery (CGI) and the filmmaking process
2. A novel technique to reduce the limitation of filmmaking
3. Components of virtual production technology

2.1 Relationship between traditional computer-generated imagery (CGI) and the filmmaking process

Before visual effects were invented, a director was limited to interacting with performers, the set environment, or physical effects. Once computer-generated imagery (CGI) became available in the late 1970s, almost anything became possible (Eschenbacher, 2018). Freed of physical restrictions and limitations, directors could now produce films that previously had been impossible or too expensive to produce. Post-production was used to create this digital content (Eschenbacher, 2018).

By the late 1980s, high-resolution image scanners and powerful computers made digital visual effects possible. Directors' imaginations expanded, and it became possible to engineer implausible pyrotechnic explosions, dinosaurs, and extra-terrestrial species and worlds (Patel, 2009). The filmmaker lost direct control over the creative process, which was now carried out in post-production, and the role of the director evolved into reviewing and approving pre-rendered images (Patel, 2009). Of the top twenty grossing films of all time, 17 feature extensive visual effects, while the remaining three are computer-animated (Eschenbacher, 2018).

A few visual effects shots grew into tens, then hundreds, and eventually the entirety of a film. The importance of preparation and visualisation increased. Previsualization assisted the filmmaker in planning visual effects shots and early artistic decisions. Previsualization and post-production remained incompatible, however, and the director could not participate directly in the creative process. With the increased use of computer-generated imagery in pre-production, on-set production procedures have become increasingly distinct from digital operations. This workflow presented a challenge for directors working on films that heavily incorporated computer-generated imagery (CGI) for visual effects and digital character creation (Patel, 2009).

2.2 A novel technique to reduce the limitation of filmmaking

For filmmakers, the primary concern is unpredictability (Priadko and Sirenko, 2021). When a director of photography must estimate the colour of the lighting to match an unseen green screen, or when a filmmaker must estimate the appearance of a virtual character, uncertainty enters. The final image form is determined during post-production when significant changes are either impossible or prohibitively expensive due to a tight release deadline. Replacing missing or temporary shots, colour correction, and missing audio can take a long time. These factors make it increasingly challenging for filmmakers to achieve the final version of the sequence and frequently result in an artistic compromise in the finished film.

According to an Autodesk whitepaper study (Patel, 2009), filmmakers and their teams required methods for directing CG operations simultaneously with live action. This demand resulted in the development of virtual production techniques. As with live-action shots, virtual production processes facilitate the proliferation of computer-generated imagery (CG) technology upstream and downstream and the latest advancements in gaming and real-time graphics performance. Creating computer-generated animation and visual effects shots may resemble creating a live-action shot while retaining creative freedom. When the virtual production takes on an interactive component, it resembles filmmaking.

In contrast to conventional computer-generated imagery, virtual filmmaking is directed by the creative team's principal members. While previs artists and computer animators collaborate on previs, it is ultimately up to the director and cinematographer to do the shooting. Real-time rendering technologies create breathtaking images that deserve to be called high-end concept art. Filmmakers no longer have to wait for hours, days, or weeks to see computer-generated images that correspond to their imaginations.

Filmmaking in the traditional sense requires a great deal of iteration. Working with visuals close to the final result eliminates the uncertainty associated with pre-production and visual effects. Both pre-production and the primary image are handled concurrently. According to Priadko and Sirenko (2021), virtual production technology enables various computer applications and automated image visualisation production processes. Virtual production allows filmmakers to resolve critical filmmaking issues and identify "pain points" in the production process. Virtual production provides intermediate images closer to the final look and eliminates missed or incomplete shots, which alleviates editing anxiety.

Additionally, there are numerous advantages to producing images in real-time. Shooting sequences are updated in real-time and displayed at a high resolution. According to Kadner (2019), virtual production is more iterative, collaborative, and nonlinear than traditional production. Because these high-quality images are generated in real-time, we can iterate, experiment, and adapt, all of which enables filmmakers (including department heads) to collaborate in real-time on visual elements rather than deferring to post-production. A real-time engine enables high-quality images to be produced from the start; rather than having isolated teams create incompatible assets, assets are cross-compatible and valuable throughout the previsualization to final output stages. As a result, more crew members are involved in the pre-production process, *Life of Pi*, *Logan*, and *Bohemian Rhapsody* use virtual production to depict an actual or implausible situation. (Priadko and Sirenko, 2021).

Virtual production can be used to create or enhance film visuals. Along with producing visual effects for films, virtual production is used to refine the look of more conventional films or films that lack visual effects. Over the last decade, virtual items have become increasingly important in major visual-effects films. Examples include *The Lord of the Rings*, *Harry Potter*, *Jurassic World*, *Star Wars*, *Pirates of the Caribbean*, *Transformers*, and *Avatar*. Even without visual effects, most films are distributed digitally.

2.3 Components of virtual production technology

According to Kuchelmeister (2020), the term "virtual production" refers to a broad range of computer-assisted production and visualisation techniques used in filmmaking. Virtual production combines live-action capture and real-time character visualisation for actors and crew. Virtual production serves as the bridge between the physical and digital worlds, combining established techniques with cutting-edge technology to assist filmmakers in making more informed creative decisions earlier in the production process.

A growing number of films incorporate computer-generated characters and visual elements. Filmmakers desire the ability to explore locations and to direct actors, whether actual or fictitious. By the late 1980s, thanks to high-resolution image scanners and powerful machines, it was possible to combine animated creatures and characters with live-action actors (Bennett and Carter, 2014). Despite the advantages of computer-generated imagery, live-action recording and character animation have remained distinct stages of the creative process.

In contrast to traditional computer-generated imagery, the director directs virtual production in real-time. Rather than waiting for the finished CG shots, this technique enables the filmmaker to make creative choices on set. Due to their virtual origins, CGI and visual effects shots can now be experienced in the same way as live-action shots through virtual production.

According to Kuchelmeister (2020), film production surpasses the limitation of visual effects by incorporating a real-time preview component into the pre- and post-production stages. An example of a recent feature film is *The Lion King* (Favreau, 2019). Director Jon Favreau used virtual production to place live-action actors in an artificial world. While directing the stage action, a director framed the shot using a tracked virtual camera and a real-time preview of the composite image. This mode of operation encourages an iterative, collaborative, and nonlinear approach.

Virtual production combines film and game technologies, and that combination has resulted in a new and game-changing approach to interactive filmmaking. Without motion capture and virtual cameras, virtual production would be impossible. While virtual production as a concept is new, the underlying technologies have been evolving for decades (Bennett and Carter, 2014). Using virtual production technologies, artists can view their work and performances as virtual characters in photorealistic virtual worlds in real-time. The crew can augment the set with LED screens, walls, or complete stages, enabling "in-camera visual effects or "final-pixel" acquisition during the primary filming as part of what is referred to as a "virtual production" (Patel, 2009).

2.3.1 Motion captured, facial expression and lip-sync

In his 2021 study, Kuchelmeister introduces Motion Capture (MoCap), a technique for digitally recording movement patterns to animate a three-dimensional digital character in a film or video game. In contrast to video recording, a Motion Capture device captures only spatial data with no visual representation. In their study, Bennett and Carter (2014) state that motion capture systems come in various configurations, but the most prevalent are mechanical, magnetic, optical, and inertial systems. The recording quality, fidelity, and detail of various systems vary, as do the capture volume, occlusion resistance, and price.

From Bennett and Carter's (2014) research, Motion Capture comes in various forms. Each has its advantages and disadvantages, suitable for varying situations:

1. Mechanical Motion Capture: Exoskeletons are skeleton-like structures that connect to the performer's body and monitor and communicate their relative motion in real time as they move. Mechanical systems are frequently employed in the medical field.

2. Magnetic Motion Capture uses sensors to determine the spatial connection between a nearby transmitter and a series of sensors frequently positioned at the performer's joints to capture appropriate movement. This technology is sensitive to electrical interference from metal items and other electrical sources. Magnetic systems are rarely utilised today because of the effectiveness of optical and inertial systems.

3. Optical Motion Capture triangulates the location in relative space using a set of reflecting markers monitored by several digital cameras. Calibration of the cameras ensures that they capture a defined region known as the digital volume, which is proportional to the number of cameras and their quality. Optical systems are the most prevalent in the entertainment business due to their ability to capture facial gestures and finger motions and numerous performers. It can catch various items, from bipeds to quadrupeds and even inanimate objects. However, it is now the costliest system available compared to the others.

4. Inertial Motion Capture utilises tiny inertial sensors connected to the performer's joints, comparable to magnetic and optical systems. Sensors wirelessly broadcast their location to receivers. This technology is portable since it does not require the placement of cameras or markers, allowing a digital volume to be created anywhere. While the inertial motion capture system is the most recent advancement in motion capture technology and is currently the least expensive, it is limited to a single actor and does not record facial gestures or finger motions.

Eschenbacher (2018) describes a novel approach for tracking using depth maps, which are created by measuring the movement of a light photon away from and toward the camera. On the other hand, a depth map is less precise and requires more computational power than a fixed tracking marker method. Microsoft Kinect, for example, uses a single visual or latency depth sensor. Using a primitive skeleton, the program identifies human anatomy and converts it to real-time physical movement (Kuchelmeister, 2020).

Kuchelmeister (2020) points out that performance capture builds on Motion Capture by capturing an actor's full range of emotionally rich expressions. This includes image-based performance capture of facial expressions, which enables non-human characters to portray authentic human emotions. Compared to traditional computer-generated imagery (CGI) productions, this method does not require hand animation to bring multiple characters to life. The technique was invented by James Cameron and Weta Digital for 2009's Avatar (Failes, 2019a). The facial features and expressions of the humanoid alien characters in this film are strikingly noticeable, despite the difficulty in converting facial expressions and lip-sync data to a digital model of a non-human character. Custom controls, artificial muscles, blendshapes, and, on occasion, manual intervention by an animator are necessary.

As stated by Kuchelmeister (2020), despite significant advances in performance capture technology, the technique requires an extensive set of customised controls, artificial muscles, blendshapes and occasionally direct animator involvement. 3D modelling software generates blendshapes by varying the position of vertices in a 3D mesh, and individual blendshapes can be combined to form expressions. Digital humans are also challenging to deal with, as many factors influence the credibility and quality of an observer's participation in the creation process. To compensate for the deficiencies, a hybrid system combining two or more tracking technologies is often chosen. The HTC Vive Lighthouse inside-out tracking system, for example, evaluates rotation using magnetic and inertial tracking through gyroscopes, accelerometers, magnetometers, and optical tracking using photo sensors and infrared lasers. As a result, spatial resolution is extremely precise.

In addition to capturing facial expressions, lip-syncing is required to allow the character to speak (Kuchelmeister, 2020). The dynamic level of the voice recording triggers a simple jaw movement such as an opening character mouth and movement of only the tongue. The Face Animation Parameter (FAP) system allows visual speech intelligibility when digitally depicting humanoids. Voices, lips and facial movements that correspond to spoken sounds are visual counterparts of phonemes. These voices are often built as blendshapes for existing characters and are verified with a voice recorder

2.3.2 Digital humans

From Kuchelmeister's (2020) research, digital 3D humanoid characters come in an infinite variety of shapes and sizes. They can be produced via a 3D computation, a 3D scan, or customised using a character engine. Within the constraints of real-time rendering, a processed 3D-scanned character can achieve an acceptable level of computer realism (Seymour, 2021b). When creating portrayed human characters, it is critical to understand the relationship between the degree of likeness to a genuine human being and the emotional response, as a computer character exhibiting human emotions is more likely to be accepted than a computerised human portrayed in an imperfectly realistic manner. There is a narrow line between a character being unintentionally unpleasant because of its defects and the character's level of reality. Humanoid non-player characters (HPC) are often ill-portrayed by computer game developers as lifeless, stiff and emotionless, which is unacceptable to a filmmaker who intends to convey a narrative with a convincing character with whom the audience can empathise. While the portrayal of humanoids in computer games could be considered realistic, their emotional expression remains far from convincing. Within a game engine, an internal skeleton, often known as a rig, is required to animate a character. A weighted and textured skin is bonded to the rig, and in response to the pose of the skeleton, this skinned mesh deforms. In game engines, the support for rigged characters and the mapping of humanoid motion animations is excellent.

2.3.3 Virtual set and 3D asset

Kuchelmeister's (2020) textured virtual set is a three-dimensional representation of an environment, which can be used for previsualization purposes or as the final digital set for a live-action film. Virtual sets can be generated using a library (the Unity asset store), a 3D modelling application, or a 3D scan of a real-world location. The approach is determined by the environment (interior vs exterior), scene size, desired level of realism, real-time rendering constraints (polygon count, material properties), and, most importantly, aesthetics. The visceral discovery and investigation of a set or location inspire the director, cinematographer, and other creative team members. This inspiration occurs spontaneously and contributes to discovering new and improved methods to communicate the tale. In the virtual world, art-directed 3D elements can facilitate a similar creative process (Patel, 2009).

According to Patel (2009), most 3D objects used in early production and previsualization are created straightforwardly and frequently as blocked forms. Rough prototypes collect motion, scale, composition, and technical data on timing. The technique significantly improves asset quality, accelerates the process, and frees decision-makers to address critical issues. A pipeline is required to produce polished, high-quality CG objects with proper texturing and lighting. In certain circumstances, grey-shaded model assets can be worked simultaneously with a live-action set that is completely blacked out with no visible lighting cues. Grey-shaded workflows are widely acknowledged as a roadblock to CGI implementation. Fortunately, new digital technologies can aid in the real-time process and asset accuracy, and production and art directors can control asset development by turning texture and lighting into assets.

Virtual filmmaking environments are built on the backbone of art-directed 3D elements, which are created and optimised by virtual production teams, which can quickly identify and resolve issues by incorporating highly visual virtual assets into a real-time display engine. Virtual filmmaking can produce both grey-scale and fully art-directed materials. The terms "pre-animated assets" and "real-time effects", which enhance the virtual moviemaking experience, frequently refer to animated characters and visual effects. For instance, one character can be pushed into a stack of boxes during a fight, causing the crates to fall. Rather than relying on manual animation, modern processes use pre-animated materials and sophisticated dynamic simulation capabilities to capture the falls of both the character and the boxes (Patel, 2009).

2.3.4 Real-time graphics

A high-performance real-time graphics engine is required in addition to accurately capturing motion (Eschenbacher, 2018). According to Eschenbacher's (2018) research, rendering takes a great deal of time in CGI production because each frame must be rendered separately. A large rendering farm can render at 24 frames per second for hours or days using hundreds of processors; rendering a single frame in Zootopia (Moore et al., 2016), for example, took up to 100 hours. Virtual production is valuable here, allowing filmmakers to edit a scene in real-time and see the results instantly. Aside from saving time, the visual quality of CG content in virtual production allows directors and cinematographers to achieve a more seamless transition between the real and virtual worlds (Failes, 2021). Fortunately, one industry has long relied on real-time graphics: video games. In video games, game engines enable the real-time visualisation of complex visuals using powerful GPUs and finely tuned rendering processes (Seymour, 2021a). A game engine is a type of game development environment. The engines help game developers with rendering, animation, physics of moving objects, networking, scripting, and video support for cinematics.

Recently, large visual effects studios have integrated filmmaking technologies into game engines, blurring the line between gaming and filmmaking. According to Eschenbacher (2018), game engines accelerate creative decision-making, iteration, and revision while decreasing production time and improving quality. As a result, virtual production is ideal for game engines. Not only do we require film editing capabilities and 3D environments comparable to those found in Digital Content Creation (DCC) tools, but we also require practical import and export functionalities. As evidenced by several projects born from these engines, several game engines have recently focused on developing tools for real-time filmmaking. Unreal Engine and Unity, for example, are well-known game engines for filmmaking (Failes, 2021).

Previs is increasingly being used in game engines for computer-generated imagery projects. According to Eschenbacher (2018) and Nitsche (2008), the previs rendition serves as the foundation for the final film to replace having to start from scratch with a second, more complex version. The developer can work within a virtual stage play by utilising a game engine and can view a scene from any angle and at any time, which aids in framing the scene optimally. Historically, feedback has been given linearly, from department to department, which implies that production must approve all changes. Implementing a game engine can reduce costs, increase production, and improve quality, while the virtual dimension experiments with lighting and effects to the point where the final product can be created entirely within the game engine without compositing. According to Kadner's (2019) article, the studio also renders an entire film episode in between three and four hours. Reduced lighting, rendering, and compositing teams could result in cost savings and increased productivity.

According to Eschenbacher (2018), the advantages of real-time graphics outweigh the disadvantages. Real-time interaction with a scene enables rapid modification. The production process resembles live-action filmmaking, except that the filmmaker has greater control and flexibility over the project. In the production of traditional live-action filmmaking, the camera cannot be moved while editing time-consuming image sequences. While game engines are increasingly used to generate computer-generated imagery, they lack the functionality and capabilities necessary to produce comparable high-end output.

2.3.5 Narrative design and sequencing in a game-engine

In video games, cut scenes are frequently used to amuse and inform the player. Game engines added the timeline feature to their toolbox to assist developers in planning events. This concept will be familiar to filmmakers who use nonlinear editing software. Individuals, environments, lighting, cameras, and audio references the game engine's timeline. A camera track may therefore contain multiple virtual cameras along with the position/orientation and lens of each of them. These virtual cameras can simulate tracking shots, zooms, and other effects in a timeline. The same blending feature is available for animations, which simplifies the sequences of motion-capture shots. The timeline enables seamless character posture transitions between takes. These narrative tools are the most exciting and enjoyable part of the process for a filmmaker (Kuchelmeister, 2020).

2.3.6 Virtual cinematography

According to Kuchelmeister (2020), the term "Virtual Cinematography" encompasses real-time live-action systems on a Motion Capture or chroma key stage and virtual cameras operating within a gaming engine. Allowing a filmmaker or cinematographer to experiment on the fly is critical. The filmmaker can manipulate lighting, lens selection, framing shots, and even the use of dollies and cranes to create images that are impossible to capture in real-time. However, this is not a genuine camera lens configuration. Virtual cameras lack shutter speed and aperture control. First, an image maintains focus throughout the frame, even when subjects move. Game engines incorporate a post-processing stack that simulates a characteristic of a physical camera to control how a scene appears fully.

Filmmakers use cameras to capture visual images of their performers, as Bennett and Carter (2014) explain in their study. While virtual cameras resemble film cameras in several ways, they capture the performance of virtual characters within a virtual world. Simultaneously, motion capture is used to capture and present the camera's motions in real-time in the virtual environment, which enables performers and filmmakers to capture digital performances intuitively, similar to live-action performances.

Virtual cinematography imparts cinematic concepts to a computer-generated scene, by combining a motion-capture camera, a green or blue screen, and a pre-visualisation virtual world, all of which enable the proper evaluation of both real and virtual actors or sets. According to Eschenbacher (2018), virtual cinematography is frequently used in previsualization, which has been an integral part of the content creation process from the start. In computer-generated films or digital previs, a CG or virtual camera captures each shot. Eschenbacher (2018) states that, after the technology had improved, James Cameron used a SimulCam to visualise *Avatar* (Cameron, 2009). *The Jungle Book* (Favreau, 2016), according to Eschenbacher (2018), incorporated a virtual camera, with which all the final film shots were planned and shot. Director John Favreau predetermined the creatures' size, scale, and location using a head-mounted display. Favreau and cinematographer Bill Pope then used a virtual camera to block the scene before the motion capture stage. The device tracked Pope's virtual-camera movements across the stage using motion-capture markers. Additionally, CG artists enhanced motion-captured movements to create scenes (Failes, 2019b).

According to Eschenbacher (2018), virtual reality technology has enabled further advancements in virtual cinematography technology. Using virtual reality tracking systems for low-cost prototypes appears to be a good idea. Due to their origins in virtual reality, these devices are also used in virtual cinematography. However, the intended use of virtual cinematography must be considered, as must various other factors, including mobility, positional precision, budget, desired virtual camera features, and application compatibility. Another critical factor is the consumer's current technological capabilities. If users already have a virtual reality tracking system, virtual cinematography technology is an excellent option.

3. RESULT OF REVIEW AND DISCUSSION

The use of blue and green screens has begun to make the film set more of an abstraction (Eschenbacher, 2018), and it has become difficult to maintain a shared vision for the project. For live action, the pre-production step is more time-demanding, and every element must be worked out in advance and every detail must be meticulously planned to ensure that the main shoot is completed on time. The development of virtual production was sparked by the film industry's growing unhappiness with a linear production approach, and it became evident that dealing with ever-growing CG content was forcing the development of unique solutions that enable an interactive, collaborative, and straightforward workflow. In particular, virtual production technology may help the director of photography improve their daily tasks by enabling them to previsualize their shots in detail – for example, by testing various light setups in a virtual world. This technique enables greater flexibility and experimentation, which is not available in a typical production due to a lack of time on set to experiment with different light arrangements and camera angles physically.

A production team working on a real-time film can make decisions. All aspects of the production, including character and set design, lighting, and cinematography, are subject to change, which requires domain expertise and technological capabilities. To reintroduce collaborative and interactive approaches to filmmaking, virtual production combines real-time and motion-capture technologies. Additionally, technological advancements in tracking systems and real-time graphics are accelerating the advancement of virtual production. The fusion of these technologies, which has been conceivable for only the last two to three years, permits the implementation of projects with budgets ranging from low to high in various fields of application.

Filmmaking is an empowering creative and technological exploration of novel and engaging narrative methods. Virtual production and its benefits for filmmaking are the prominent next stage in cinematography's continual growth. This technology does, however, have limitations and remains in its infancy (Kuchelmeister, 2020). Implementing virtual production techniques is a huge undertaking, the film industry is still in the early phases of adopting virtual production methods, and the methods are anything but standard. To embark on virtual production calls for expertise, talent, patience, and a willingness to take calculated risks, but the rewards are substantial. The relentless march of technological advancement will continue to make the technologies outlined in this paper more accessible. Low-budget productions are already employing a number of these strategies to enhance the quality of the film.

As virtual production workflows become prevalent and experts gain confidence in the new technology, the techniques will spread throughout the film production pipeline. Real-time, immersive digital toolkits and the additional research and preparation they enable can benefit every department. In films such as "Avatar" and "The Jungle Book", it is evident that the benefits exceed the drawbacks. The new toolkits demonstrate the effect of technology on the directing team, cinematographers, visual effects supervisors, actors, and the art department, as production designers learn to use it. These professionals can evaluate their creative contributions the same way the director and, ultimately, the audience will. Virtual production does not require prohibitively expensive motion-capture technology. Smaller companies and art departments working on pre-approval projects can afford to experiment with virtual workflows, and the technology can potentially be upscaled as the project progresses.

As technology progresses in scalability and accessibility, more creative professionals will use Virtual Production. Virtual production will facilitate collaborative work with detailed visualisation and minimise the possibility of misinterpretation. With widespread adoption and continued use of virtual production tools, the industry will reach a stage when "virtual will be abandoned and this will simply be called production," as David Morin, Chairman of the Virtual Production Committee, remarked (Eschenbacher, 2018).

4. CONCLUSION AND FUTURE WORK

The primary objective of this review is to assess how virtual production aids filmmaking. The article's objective is accomplished through an extensive review of related literature, and the review's findings indicate that virtual production is now regarded as a novel method for filmmaking that offers many new practices. As a result, this method achieves a comparable result while being more time and cost-efficient.

The current revolution in real-time filmmaking and virtual production is a significant addition to this exploratory urge, as it can enable filmmakers to realise their creative vision outside the flat screen. As this is merely a review article, future studies should explore the effects of these technological advancements on filmmaking and consider other possibilities, such as utilising virtual reality devices, such as the Oculus Rift, to reduce the time required to make a film and enhance productivity and other outcomes in other areas of film production, and not only in pre-visualisation.

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