



# The VES Handbook of Virtual Production



Edited by  
**Susan Zwerman, VES**  
**Jeffrey A. Okun, VES**

A Focal Press Book



# The VES Handbook of Virtual Production

*The VES Handbook of Virtual Production* is a comprehensive guide to everything about virtual production available today – from pre-production to digital character creation, building a stage, choosing LED panels, setting up Brain Bars, in-camera compositing of live action and CG elements, Virtual Art Departments, Virtual Previs and scouting, best practices, and much more.

Current and forward-looking, this book covers everything one may need to know to execute a successful virtual production project – including when it is best to use virtual production and when it is not. More than 80 industry leaders in all fields of virtual production share their knowledge, experiences, techniques, and best practices. The text also features charts, technical drawings, color images, and an extensive glossary of virtual production terms.

*The VES Handbook of Virtual Production* is a vital resource for anyone wishing to gain essential knowledge in all aspects of virtual production. This is a must-have book for both aspiring and veteran professionals. It has been carefully compiled by the editors of *The VES Handbook of Visual Effects*.

**Susan Zwerman**, VES, is an experienced Visual Effects Producer with a passion for cutting-edge film production. She is highly respected for her expertise in visual effects and virtual production budgeting and scheduling. As chair of the DGA UPM/AD VFX Digital Technology Committee, Susan organizes virtual production seminars to introduce members to this exciting and evolving new technology. Susan received the Frank Capra Achievement Award in recognition of career achievement and service to the industry and the Directors Guild of America in 2013. She is a member of the Academy of Motion Picture Arts and Sciences, the Producers Guild of America, the Directors Guild of America, and a member and Fellow of the VES.

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# About the VES

The Visual Effects Society (VES) is a nonprofit professional, honorary society dedicated to advancing and promoting the art and science of visual effects and to fostering and striving for excellence and knowledge in all matters pertaining to visual effects. Further, the VES strives to actively cultivate talented individuals in this discipline; to educate and develop public awareness and understanding; to support and encourage technological advancements in the field of visual effects; and to establish a collective organization that recognizes, advances, and honors visual effects as an art form, in order to promote the interests of its membership.

## Mission Statement

The VES, a professional, honorary society, is dedicated to advancing the arts, sciences, and applications of visual effects and to improving the welfare of its members by providing professional enrichment and education, fostering community, and promoting industry recognition.



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# Foreword

**Kim Libreri, CTO at Epic Games**

Visual effects have constantly evolved since their inception. Early effects pioneers like Georges Méliès and Oscar Rejlander invented methods to leverage motion picture technology and create visual illusions that could not exist in real life. Visual effects consistently wowed audiences in ways that would otherwise be impossible to achieve, and we still have not yet discovered their ultimate limits.

Many innovations throughout the history of visual effects altered the trajectory and perception of what is possible. Stop-motion, optical compositing, motion control, CG animation, digital compositing, physically based ray-tracing, and performance capture are all techniques invented and refined to achieve ever more impressive spectacles. This process of discovery and reinvention continues to this day with the latest advances in virtual production, in-camera visual effects, and real-time game engine animation.

Digital visual effects over the past three decades revolutionized what we can create. At the same time, the democratization of digital content creation tools shifted the workflow and economic paradigm. Decreasing margins, more demanding audiences and clients, and the ubiquity of post-production tools and facilities led to a status quo within the industry.

The ubiquity of spectacle also threatens to erode the genuine awe and wonder that brought most of us into this business in the first place. We must constantly innovate to counter this ubiquity. Pioneers like Douglas Trumbull and his associates inspired us to strive to create something new by taking the first steps into virtual production.

As an inventor constantly seeking new ways to develop hyperrealistic scenery to captivate the imaginations of moviegoing audiences and elevate the theatrical experience, Trumbull saw the

# Foreword

immense promise of real-time tools. “If it’s not real-time, then it’s got to be near real-time, so we can make aesthetic and editorial judgments and rapidly proceed with production,” Trumbull *said back in 2012*.<sup>1</sup> His goal was to generate spectacular content that demanded viewing on the largest screen possible.

The dream of real-time, closed feedback loop visual effects completely live and in-camera, as envisioned by many pioneers, is here today, but we are only scratching the surface. To succeed, a visual effects artist must master the technical workflows and comprehend the underlying aesthetic and business processes. **Today, the opportunity has never been more significant for visual effects artists because virtual production with real-time animation changes the game.**

## An Evolving World for Visual Effects Artists

An appreciation for the state of visual effects today benefits highly from some observations about how real-time animation and virtual production may impact visual effects artists going forward. Artists will become more present and crucial throughout the production process, whether during pre-production or production, rather than relegated to post-production. This heralds a return to the creative inclusion of visual effects artists in pre-production and production phases because the tools’ rendering speed will not hold them back. We will no longer wait for overnight renders or modeling changes because everything can be manipulated and rendered in real-time.

The speed that creative work can be delivered also heralds new configurations for working relationships. Creatives will expect the immediate feedback loop of real-time and no longer await the delays of traditional long-form post-render pipelines. Visual effects artists may feel more pressure to deliver their best work within tighter timeframes while collaborating more directly with creatives. These changes can also lead to a firmer commitment to significant decisions earlier in the process, meaning fewer redundancies and less busy work for artists.

Visual effects artists should master lighting and cinematography as they exist in the real world because the engines rapidly evolve to match reality. Prior animation tools often lacked realistic lighting simulations and leaned on the artists to mimic realism. Because game engines offer physical-based lighting and realistic camera simulations, they can better approximate real-world cinematography. The onus is on the artists to understand lighting ratios and real-world materials as they interact with the cinematographer directly instead of following up on their work while siloed off in post-production.

Visual effects will become less abstract and more tactile for the artists and the creatives they collaborate with. Real-time engines enable highly realistic visuals out of the box, meaning proxy imagery and provisional visualization will be far more accessible to all stakeholders. Less technical filmmakers will engage more with visual effects, leading to new voices and a greater diversity

of ideas. The speed of iteration and interactivity will also increase, demanding greater precision and attention to detail.

Although we strive to follow in the theatrically motivated footsteps of Douglas Trumbull, our audience's consumption habits continue to evolve. The convergence of video games and filmed entertainment will increase as the metaverse takes shape. No one can predict this interactive new media platform's final form. Still, we can expect it will require the same or better visual effects quality to succeed. As media boundaries blur, visual effects artists will find opportunities across various industries driven by real-time animation skill sets.

## ***Conclusion***

Virtual production with in-camera visual effects and real-time engines offers a creative renaissance for visual effects artists who fully embrace its strengths. We need a new creative revolution to deliver fresh ideas and new possibilities. Real-time tools, specifically game engines, are the catalysts that will touch every aspect of the production process and open up new opportunities for visual effects artists and their craft.

As with any pioneering technology, artists should embrace the future and not be overly precious about preserving the past. Significant innovations often come from a level of naivete or at least pushing through the downside of existing paradigms. Visual effects artists should strive to embrace change and avoid analysis paralysis as much as possible.

In other words, do not be afraid to leap into the unknown and take risks as perfection is often the enemy of evolution. The willingness of filmmakers to bring the power of real-time engines onto their sets and in front of their cameras will help us all push through exceptional barriers and deliver the next level in the rich tradition of visual effects pioneers.

## **Note**

- 1 <https://www.btlnews.com/crafts/post-production/douglas-trumbull-fuels-new-filmmaking-paradigm-with-nvidia-quadro-gpus/>.



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# Introduction

**Miles Perkins, Industry Manager, Film and Television at Epic Games**

## A Visual Effects Paradigm Shift

Imagine a recording session with jazz great Duke Ellington and his orchestra. Members play off of one another through the subtle collaborative interchange of rhythm, dynamics, and improvisational phrasings – except for one band member. That member can only contribute their part after the recording is complete, note-by-note, and without the context of the collaborative exchange that comes from creating alongside peers.

Due to the limitations of available hardware, this is how traditional CG visual effects have operated for the past three decades, where many critical creative decisions are made outside the primary iterative process. With CG workflows only being as fast as the slowest part of the pipeline, many bottlenecks have centered around rendering and simulation, where iteration times are often measured in minutes, if not hours. But with advancements in graphics hardware, this paradigm is rapidly shifting where high-quality photorealistic imagery is being generated in real-time. Driven mainly by the talents of software developers, inspired by these advancements, game engine technology has powered a real-time revolution appropriately dubbed Virtual Production.

Virtual production is any filmmaking process or workflow that removes the barrier between virtual and physical. A filmmaker can engage with a virtual environment no differently from a physical set. Enabling this new wave of virtual production are technologies that strip away the byproducts that have kept CGI primarily a post process.

For shows that leveraged computer graphics, navigating through visual effects workflows, and communicating in a very different language than traditional filmmaking, caused an artificial impediment between post-production and the other heads of production departments (HODs). Until recently, physical production craftspeople had limited input or visibility into the final product – often only seeing it once it premiered to an audience. But through real-time workflows, production

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dynamics are rapidly changing, empowering departments teams to bring the best of their crafts to the project more fluidly and collaboratively, whether in the physical or virtual world.

As this evolution continues and other film departments increasingly adopt virtual production workflows, CG artists will find more opportunities to participate earlier in the creative process. Virtual production empowers visual effects to be part of the creative process before, during, and beyond the moment of live-action creation.

## How Real-Time Enhances Traditional Visualization

Along with a survey of existing virtual production tools within a game engine, it is also valuable to enumerate how virtual production in real-time can enhance traditional visual effects workflows.

Because the quality of previs imagery generated in real-time tools is much higher and more realistic, shots generated during this visualization process can carry forward into production and post-production. Critical creative decisions can be made much earlier, avoiding the need to recreate work or rebuild assets multiple times across the life cycle of a project. It also allows filmmakers and department HODs to make and own decisions much earlier in the process, which, if managed well, can lead to a more efficient and collaborative approach.

## Cinematic Simulation Possibilities

An obvious benefit of real-time technology is the ability to render photoreal images in a fraction of a second. Another feature of game engines that is often overlooked: Cinematic design through simulation. Without simulation, a visualization will only show what the artist animates explicitly via keyframe animation or performance capture. Simulation, machine learning, and artificial intelligence open new ways to achieve shots and experiment just as a live-action director would on an actual set.

In the same way, any “cause-and-effect” action can be set up to provide a more organic performance between the characters and their environments, like flocking, destruction, growth, and environmental effects – just like the real world, but with more creative control.

Simulation can lead to serendipity and happy accidents that a more rigid visual effects workflow might overlook. An excellent example is *The Matrix Awakens* (2021), a unique project that coincided with the release of *The Matrix Resurrections* (2021). Viewers can interact with a massive procedural/AI-simulated environment representing the San Francisco-like city of the movie. The amount of detail within the simulation is enormous, with many buildings, pedestrians, traffic patterns, etc. And while it is a persistent world, none of it is baked; the engine can render everything

photorealistically on the fly to react to the viewer's input. The same methods can create highly interactive visualizations, iterate on final visual effects shots, or populate LED volume environments with virtual elements like extras and traffic.

## Visual Effects Roles in Virtual Production

Virtual production encapsulates many different roles and enables artists with a real-time skill set to transition fluidly through many other areas, including but not limited to production design and art department, cinematography, pre-production and production visualization, and more broadly, game design, automotive and manufacturing, architecture, AI, and more. This means more significant opportunities for professional development, more jobs, and stimulating new challenges.

For studios working in this paradigm, it allows them to repurpose intellectual property and digital assets for many forms of distribution, including movies, streaming, games, location-based entertainment, and ultimately, future transmedia opportunities and whatever form the Metaverse takes. For artists this means less redoing of work and a longer life cycle for their creations.

Because virtual production with in-camera visual effects demands camera-ready assets before production can commence, CG artists also support the production's art department. Increasingly, visual effects artists are on set with in-camera visual effects, working in a live-action environment. Artists collaborate in real-time with the cinematographer, director, production designer, and the like. This elevates visual effects to play a role in the entire production process. The shift means additional opportunities and new modes of contribution for visual effects artists.

## Creative Iteration in Real-Time

For visual effects professionals, iteration can be a double-edged sword. There is a desire to offer plenty of creative options, but doing and redoing work can often feel repetitive and is time-consuming. Because there is much less time penalty associated with real-time rendering and the image quality is much higher without a proxy mode, iteration can be much more satisfying to deliver. The iterative feedback loop with the filmmaker can be more immediate and effective, allowing decisions to be made in the moment.

Shot-to-shot continuity is also easier to achieve when each shot can be adjusted in relation to surrounding shots without layout or rendering penalties. Visual effects teams are accustomed to seeing individual shots out of context because the surrounding media is incomplete. Critical creative assessments are challenging because the entire picture needs to be clarified. Real-time rendering at high-quality can be completed much earlier in the pre-production process, so artists see everything in context and can quickly support the editorial cut.

## Workflow Evolution

Technological changes ultimately impact the workflow and offer new methods of working more effectively and collaboratively. Visual effects move from an assembly line analogy to a creative feedback loop where less effort is lost on the broad strokes. Artists should expect a cycle of big and small loops, where iteration is constant until the desired outcome is achieved organically vs. out of end-of-schedule necessity.

To make this process work, it is critical that visual effects and other departments share an intuitive and familiar filmmaking vocabulary. Unreal Engine has been developed over different releases to bring filmmaking terminology into virtual production so that ways of referring to lights, color values, and other important properties use cinematic terms. Epic Games, along with the ASC, Netflix, and the VES, supported the creation of the Virtual Production Glossary as a standard reference for professionals arriving at the world of virtual production. These different aspects of the engine are conscious attempts to bridge the gap between the virtual and physical worlds.

### ***Conclusion***

Virtual production delivers cinematic visual effects with the spontaneity and collaborative nature of live-action production. This benefits the completed projects and the creative individuals working hard to deliver on schedule and within budget. An ideal solution is a hybrid approach that leverages the power of real-time creation while preserving all the advantages of post-rendered effects.

Advanced real-time workflows are designed to fit into a non-siloed production pipeline. The spirit of collaboration and spontaneity is often the spark that separates a good movie from a great one. Real-time virtual production tools can assist this effort and empower craftspeople to deliver their best work, supported by best-in-class workflows and state-of-the-art technology.

# What Is Virtual Production

## Definition of Virtual Production / Types of Virtual Production

**Sally Slade – Voltaku Studios**

### **Definition of Virtual Production**

Virtual production is the augmentation or replacement of traditional visual effects or animation workflows by the use of real-time, digital technology.

There are a range of existing implementations of the above definition, spanning from live green screen replacement to full digital replacement of actors, environments, and even cameras. What follows are practical examples to impart further clarity.

Live green screen replacement is perhaps the most widely publicized manifestation of virtual production today. In this practice, rather than a traditional green screen, an LED wall is used to substitute for a material environment. Virtual production operators can transmit final-frame 3D imagery to the wall in real-time, allowing the cast and crew to become immersed in the space, both story-wise as well as physically.

The imagery on the wall is more than just a static background: The render is presented from the perspective of the in-world shot camera, which means that as the shot camera moves, the digital environment rendered to the LED wall updates its perspective. This enables a level of parallax and realism unrivaled by traditional matte paintings.

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**Figure 1.1** A motorcycle is lit by LED walls and ceilings on the set of Imagination's *Into the Volume* (2021)  
Source: (Image courtesy of Imagination, Global Experience Design Company)

This practice offers a few advantages. In terms of story, an LED wall enables cinematographers, directors, and actors to have a shared sense of diegetic<sup>1</sup> space. This enhances the team's ability to make coherent, dynamic decisions on set, often leading to a more nuanced performance or camera movement that might not otherwise take place if the environments were added in post-production.

In physical terms, an LED wall offers realistic light-bounce. This ensures the talent, props, and set are responsive to environment lighting. It also eliminates the dangers of visual artifacts left behind from legacy green screen spill or challenging rotoscope work.

LED walls are not the only approach to set-replacement or extension: Real-time in-camera green screen replacement is a chronological predecessor to LED walls, and it is a workflow that has continued to evolve.

First publicized by Disney's *The Jungle Book* (2016), the in-camera green screen replacement technique involves the digitization and real-time transmission of the shot camera's position and lens information from the set directly into a game engine. From there, a virtual scene is instantly rendered and sent to monitors on set, allowing the cast and crew to see what might be considered a pre-visualization, or even the final frame content of a sequence or shot.

At the time of this writing, final frame is not often captured directly from a real-time renderer when it comes to live-action film productions. The quality bar is elusive in an only partially raytraced

# What Is Virtual Production

environment with asset production pipelines tuned to the needs of AAA video games rather than Hollywood productions.

However, virtual production extends beyond Hollywood productions. There are live performances from actors and musicians participating in virtual production workflows across the entertainment industry. By leveraging a high level of stylization, these creators can easily get away with rendering final pixels in-camera in real-time.

A historic example of this process would be musician Katy Perry's performance of her song "Daisies" during the finale of *American Idol* (2020). In the first known large-scale broadcast of this technique, Perry delivered vocals while navigating through and interacting with a complex virtual environment, consisting of shifting horizon lines, and moving objects at different depths and scales in time with her music.

This production used an LED wall and a single prop chair to complete the physical set in combination with real-time in-camera composites to achieve a full, omnidirectional set extension, complete with moving abstract elements and several visually unique virtual rooms.

As technology evolves from desktop monitor displays to mobile device displays to head mounted displays, terminology evolves as well. It is important to note that in-camera composites may also currently be referred to as "augmented reality."

The definition of augmented reality is the real-time digital augmentation of the user's perception of reality. It is not relevant if the user's perception of reality is through a device screen or their own eyeballs. Nor is it relevant if the augmentation is photoreal, tracks with the camera, or has light sources that match its real-world environment. Examples of augmented reality range from informational displays on car windshields to Snapchat lens filters to the science fiction brain-implant technologies seen on television shows like *Black Mirror* (2016).

However, as the limits of creative expression continue to be removed by technical innovation, expertly integrated augmented reality assets have begun to distinguish themselves from more primitive forms of augmented reality (AR).

Augmented reality which takes integration a step further via tracking with the camera and enabling occlusion of the virtual asset via real-world objects can be referred to as mixed reality (MR). However, given the rate at which mixed reality technologies are developing, many creators do not bother to distinguish MR from AR and leave it up to context.

One could easily describe Katy Perry's performance of *Daisies* (2020) as either an AR or MR experience – both of which fall under, but are not limited to, the umbrella of technologies that make up virtual production workflows.

Virtual production is more than just the replacement, or augmentation, of environments: Virtual production workflows are already sophisticated enough to be integral to character performance as well.

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By using full-body tracking and facial motion capture, on-set operators can capture a character's performance. The captured data can be stored or immediately transmitted to a character rig, allowing the virtual character to be puppeteered in real-time.

A practical example of this can be found in the production of Netflix's *Super Giant Robot Brothers* (2022), created by ReelFX. This production involved a motion capture stage where multiple actors performed simultaneously while a cinematographer captured everything using a virtual camera with a portable monitor display that rendered the view from within the game engine in real-time.

The cinematographer was not constrained by the real-world motion of the camera and was able to augment camera movements using thumbstick controllers mounted to the camera rig. In this way, the DP was able to overcome the physical limitations faced by non-virtual camera operators to travel large distances instantly, shoot from drone heights, or isolate the camera motion to a single vector.

The ability to watch an actor's performance mapped onto a digital character is also not limited to strictly in-camera compositing for on-screen display. Creators around the world have begun filming and broadcasting from directly within the digital world of virtual reality (VR). Virtual reality is distinct from augmented reality in that it entirely replaces one's reality with a fully virtual landscape and cast of characters.

Over the last few years, creators such as PHIA, of *The Virtual Reality Show* (2020–present), have been fabricating environments, props, and characters and filming final frames directly within game engines via handheld, and statically placed, virtual cameras. In 2022, a feature-length documentary called *We Met in Virtual Reality* (2022), was filmed entirely within *VRChat* – a fully immersive social VR platform.



**Figure 1.2** Pioneering independent virtual productions such as *The Virtual Reality Show* (2020) are filmed entirely within VR, using virtual cameras, virtual sets, and avatars driven by motion capture  
*Source:* (Image courtesy of PHIA)

# What Is Virtual Production

The seeds of these techniques date back to the turn of the century when independent filmmakers created an 18-episode season of a television show called *Red vs. Blue* (2003), filmed entirely within the virtual world of the *Halo* video game franchise. The technique at that time was colloquially referred to as “Machinema.”

Meanwhile in Hollywood, the crew on Disney’s *The Lion King* (2019) often immersed themselves in virtual reality for virtual location scouting, animation blocking, and final camera movements. This full immersion technique gives the cast and crew a sense of presence that transcends both in-camera compositing and LED walls. The immediacy of full virtual immersion lends itself well to a shared understanding of virtual spaces and characters. With the cast and crew fully aligned, collaboration and dynamic decision-making can flow organically, putting the indefinable energy of a traditional film set in closer reach.

Now that the concept of virtual production across AR, MR, and VR mediums has been covered, it will be helpful to define XR, a catch-all term the film and gaming industries are continuing to define.

Historically, XR has a few definitions: It is the “X” variable holder meant to represent the “A,” “M,” or “V” within AR, MR, and VR. It is also referred to as “cross reality,” meant to describe a mixed and asynchronous interaction of players across both virtual and augmented realities. Most recently, and perhaps most commonly, XR may be elongated to “extended reality” and is a blanket term referring to anything that modifies one’s native, non-digital, everyday experience of organic reality.

Just as XR is a forward-looking term, virtual production is a forward-looking workflow. Developers are working tirelessly to build XR toolsets that disrupt virtual production from an active, pre-production, and post-production standpoint.



**Figure 1.3** The crew develops shot cameras in virtual reality on the set of Disney’s *The Lion King* (2019)  
Source: (Image courtesy of Michael Legato)

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It is not just XR software that will disrupt the virtual production industry; upcoming XR hardware will also play a critical role. The democratization of head-mounted displays will be a game changer for virtually driven productions. Seeing virtual elements integrated within a physical space will be a revolution in communication and reaction times on set.

For pre-production, consider everything that goes into building a safe and effective set environment. Using digital twins (the replication of a physical location in a virtual environment), set designers might work from home using XR technologies. Safety officials can remotely determine which areas of the set need to be reinforced for particular action scenes. DPs can map out where to lay dolly tracks. All of which can happen with near-vertical integration rather than the traditional waterfall workflow of Hollywood.

For post-production, the full potential of virtual production has yet to be realized. Consider the role of an editor cutting together various shots to build tension and clarify narrative direction. If only they could alter the angle a shot was captured from or the ability to render a sequence from a different character's perspective, then, perhaps, they could make the killer cut unforeseen during pre-production. This will become possible due to emerging volumetric video file formats which allow virtual cameras to re-render sequences using deterministic transform data. The future for virtual production is incredibly bright and largely unexplored!

## What Types of Scenes Work Well for Virtual Production

**Sally Slade – Voltaku Studios**

Virtual production is not a solution in search of a problem. There is a time and place to use this workflow over other solutions.

The best use for virtual production, given its current technological limits, would be for the following types of sequences: Sequences with completely digital characters or predominantly digital environments, sequences that are cost prohibitive or inconvenient to shoot on location, or sequences where it is physically prohibitive to execute on set.

Sequences featuring digital characters or predominantly digital environments are excellent choices for virtual production. What follows are practical examples from each.

With regards to completely digital characters, consider *Alter Ego* (2021). On this production digital characters were integrated on set in such a way that a panel of judges could receive a live-operator's musical performance and interact with the corresponding virtual characters verbally as well as visually.

The unscripted nature of the interactions made virtual production and its real-time capabilities an excellent choice. Beyond that, the stylized nature of the digital characters was forgiving enough that final frames straight from the game engine met an acceptable bar of visual quality.

# What Is Virtual Production



**Figure 1.4** A motion-capture-driven avatar is composited in-camera in real-time in front of a live audience for a performance on *Alter Ego* (2021)

Source: (Clip Courtesy of Fox Entertainment. ALTER EGO © 2021 by Fox Media LLC)

It is important to note that the stylization of digital human characters is an artistic way to overcome the limitations of realistic human rendering from within game engines. For this section, readers may assume that the challenge of using photoreal CG humans has not yet been overcome by real-time game engines.

Scenes with predominantly fabricated environments are also perfect for virtual production. As an example, one might consider *The Batman* (2022), from Warner Brothers. This production made use of virtual production for various sequences: A car chase sequence and a sunset rooftop sequence stand out as two unique use-cases for the same virtual production solution.

Process shots (shooting dialogue inside a moving car, airplane, train, etc.) are excellent for virtual production because no terrain needs to be physically traversed. The prop car stays in a singular location, fans are blown at the actors, and the environment streams by on LED walls. This need not be limited to *The Batman* or even to automobiles. The same concept applies to motorcycles, trains, buses, helicopters, spaceships, and heretofore uninvented forms of high-speed locomotion.

As compared to a green screen solution, virtual production gives the cast and crew a shared point of reference and the ability to react to that reference to add specificity and nuance to a performance. As compared to an on-location solution, no time or budget is wasted moving from point A to point B during shooting or moving from point B back to point A between takes. This of course improves turnover time and the safety of the cast and crew during filming.

The sunset rooftop sequence in *The Batman* is notable for two reasons. For one, the crew could shoot the sequence without regard to the passage of time – the lighting for any shot remains

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**Figure 1.5** An LED volume displays a moving environment while a stationary prop car is manipulated by an actress  
Source: (Image courtesy of PRG)

unchanged in a virtual environment (unless one would like it to change). For the first time in film history, cinematographers do not need to concern themselves with time pressure for the sake of capturing realistic lighting at dusk. Further, if there were qualms about the positioning of the setting sun or clouds, these parameters could be completely art directed and changed with little hassle by a virtual production operator.

Another reason virtual production was an ideal solution for the rooftop sequence in *The Batman* is that Gotham City itself is visually distinct. To shoot Gotham on location would require significant post-production work, not to mention pre-production work for location scouting, securing permits, and transportation of cast and crew. Using virtual production, such hassles are eliminated. Even more exciting, a director can make decisions at production time regarding things like skyline silhouettes or the positioning of nearby hero building assets based on what they see in the viewfinder at the time of shooting.

A final type of sequence that works well with virtual production is scenes that are physically prohibitive. This could mean scenes that take place in mid-air, underwater, or within the vacuum of outer space, to name several physically prohibitive environments.

A great example of a physically prohibitive sequence can be found in Marvel's *Black Adam* (2022). In the film, Black Adam is a superhuman flying through the sky with mercenaries in pursuit. The

# What Is Virtual Production

laws of physics prevented the crew from shooting this sequence practically, and virtual production was leveraged to great use. The visual effects team shot the sequence using LED walls, Unreal Engine, and various suspension devices to lift the cast. Virtual production was a great choice because it provided realistic lighting and flexibility on set, allowing the project to move forward without blue screens or death-defying stunts.

Sequences for which virtual production would be a poor choice are scenes where sets are easily assembled or transported, where the natural lighting circumstances are largely unchanging, or scenes that feature dialogue between humans without significant focus on the surrounding environment. One might argue that a film such as *12 Angry Men* (1957) has no good reason to engage with a virtual production pipeline.

As the challenges and costs associated with virtual production continue to decline, choosing when to use virtual production as a solution will become a far less discerning process. The market is already saturated with consumer applications for mobile devices that do real-time sky replacements, realistic insertion of interactive virtual objects, and undetectable modifications to human faces. With machine learning and edge computing technologies on the rise, the complete democratization of virtual production for everyone from professionals to hobbyists is inevitable.

## Green Screen for Virtual Production

**Oscar Olarte – MR Factory**

### **How to Shoot Green/Blue Screen Using Virtual Production**

Chroma key has been used since the very earliest days of digital video production. It is therefore a trusted, familiar, and highly evolved solution for virtual productions. Real-time chroma keyers have evolved to incorporate mature and highly complex algorithms that manage the detail, spill, shadows, and reflections so that the filming crew is afforded the opportunity to concentrate on storytelling. Combining these algorithms with the latest generation of processors makes it possible to achieve very high-quality virtual productions using a chroma key.

LED Volume video displays are very good for virtual production, but the main drawbacks when compared with chroma-key-based virtual production are that the quality of the background is limited to what it is possible to compute in real-time and the lack of flexibility to change anything once everything has been shot.

Tests have been completed to discover the difference between real vs. virtual screens. Virtual green/bluescreen production produced almost the same results as the original shot.<sup>2</sup> An audience would be challenged to identify which is real and which is virtual.

To obtain such a high-quality real-time result using chroma-key-based virtual production, great care must be given to the set up of the green screen/blue screen shoot.<sup>3</sup>

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**Figure 1.6** BS Virtual Production and Final Composite filmed on BS Chroma Key Stage  
*Source:* (Image courtesy of MR Factory)



**Figure 1.7** BS Real-Time Compositing for Virtual Production  
*Source:* (Image courtesy of MR Factory)

## ***GS/BS Background***

### **CHROMA KEY**

Cyclorama sizes larger than 300 square meters are best to get a real-time chroma key. The height of the cyclorama should also be as high as possible so that there is always a green/blue screen background to composite with the foreground, especially with low-angle shots. The curve for the endless infinite background is also very important: Wide curves are best to get infinite backgrounds.

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As a rule of thumb, everything outside the camera frustum should be covered by black curtains or fabric to block any color spill.

## **USE OF LED SCREENS AS A BLUE/GREEN SCREEN FOR CHROMA KEY**

An LED volume stage can also be used as a chroma key background, either in green or blue. The major advantage of using LED as a chroma key background is the possibility of switching the background color to green or blue. However, the quality of the light of LED panels is not as good as practical green/blue screens because it has a very low TLCI (Television Lighting Consistency Index).

## ***Lighting for GS/BS***

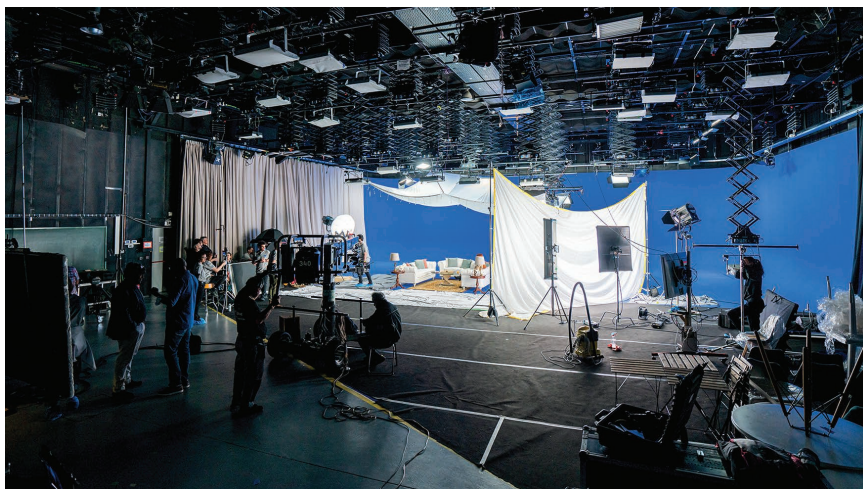
### **TLCI (TELEVISION LIGHTING CONSISTENCY INDEX)**

The quality of light is measured in TLCI<sup>4</sup> units. The spectrometer like the Sekonic C-800 is an indispensable tool to measure TLCI and get perfect chroma key illumination. Chroma key is based on color, so the quality of light to render the colors is important. To get the best chroma key results, full RGB lighting panels with TLCI above 95 units are recommended.

To match the original light of a plate, take readings using the Sekonic C-800, and then reproduce the same light measurements, with the same intensity and color temperature, on the set of the chroma key virtual stage.

### **CONTROLLING THE LIGHT SPECTRUM**

White lights contain the entire color spectrum, but this spectrum is not always perfectly balanced. It has a dominance, or spike, in the spectrum for certain colors. When shooting a greenscreen



**Figure 1.8** Fabrics blocking color spill in Chroma-Key-Based Virtual Production shot  
*Source:* (Image courtesy of MR Factory)

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shot, a spike in the green spectrum should be avoided at any given color temperature. The same is true for shooting on blue screen.

It is possible to control the color spectrum of any given color temperature with full RGB LED lighting panels such as Fos 4 from ETC. These panels have both very high TLCI and the flexibility to manage the color spectrum at any given color temperature.

## **ILLUMINATING WITH LED VIDEO DISPLAYS AND LASER PROJECTORS**

LED video displays are a very good source of illumination when there is a need to recreate reflections in a chroma-key-based virtual production. Using high-luminosity LEDs on the ceiling or behind the camera for reflections is a perfect solution for illuminating objects, while illuminating with laser projectors is a perfect solution to get real-time shadows, such as in a car scene.

## **Real-Time GS Compositing Systems Using Virtual Sets for Background**

### ***Examples of Types of Renders***

There are many ways to create and render virtual backgrounds in virtual production. To begin, choose the type of render engine, that can be either unbiased or biased.

Unbiased render engines let the light bounce in a physically correct simulation. Unbiased render is quite intuitive, and the learning curve is very shallow. Unbiased render takes less time to create a photoreal render. However, much more time and computing power are required. Biased render engines allow tweaking many of the parameters to recreate reality as close as possible. Biased render takes more labor for an artist to arrive at a photoreal render – however, the render takes less time and computing power.

It is possible to “bake” that render into polygons of a 3D scene in many Unbiased or Biased render engines. It is difficult to say which is the real photo and which is the created 3D set.

## **REAL-TIME RENDER ENGINES (WITH BIASED OR UNBIASED)**

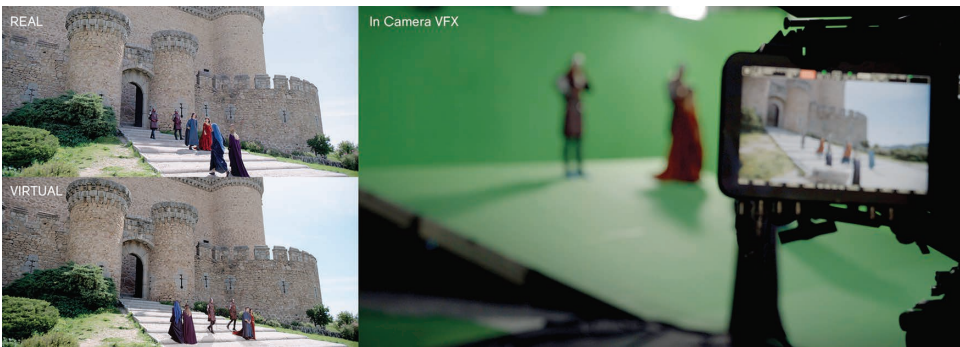
Unreal Engine, which is the de-facto standard for real-time render engines in virtual productions, can use both biased and unbiased engines.

Unreal Engine biased render is very good for real-time previs or final quality (ICVFX) by LED Volumes, but the quality is quite limited compared with unbiased production render engines like Arnold, OctaneRender, and Cycles, among others. For example, the OctaneRender plugin for Unreal Engine is intended for chroma-key-based virtual production workflows where Unreal Engine is used as a previs, while the final render relies on OctaneRender. A real-time path tracer, Brigade Engine, is included in the OctaneRender plugin for Unreal Engine, further augmenting its cinematic rendering pipeline for real-time rendering workflows. It is also possible to use the RNDR network for ultra-high-speed rendering.

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**Figure 1.9** Real vs. Virtual test set created by MR Factory using the Unbiased OctaneRender Plugin for Unreal Engine, using a RTX 4090  
*Source:* (Image courtesy of MR Factory)



**Figure 1.10** Real vs. Virtual photogrammetry test on Chroma-Key-Based Virtual Production  
*Source:* (Image courtesy of MR Factory)

## CHROMA KEY COMPOSITION

Real-time chroma key integration is one of the most important things in green/bluescreen virtual production. There are many good hardware chroma keyers, and at the time of this writing, one of the best is Ultimatte-12 4k. It is a full-featured 4K HDR (Rec 2020) 4:2:2 10bit chroma key. Chroma-key-based virtual production does not allow 4:4:4 12-bit (or above) workflows since most of the cameras, including the high-end film cameras, do not allow 4:4:4 live feeds. The best approach to retain the full original RAW quality of the camera while shooting with chroma-key-based virtual production is to record the mask and render the background in full ACES AP0 2065–1 with the EDL. That makes it possible to shoot during the day and render at night (like developing film).

## Summary

At the time of this writing, chroma key is still the preferred solution for traditional visual effects shooting. However, chroma-key-based virtual production is one of the most promising solutions in the virtual production arena. The new high-end 8K HDR real-time chroma keyers combined with the power of the new RTX 4090 and the Multi-GPU Real-Time PathTracers will be a game changer.

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This approach will push the envelope and improve the quality of chroma-key-base virtual productions to near-perfect quality while maintaining the flexibility and productivity of this technology.

## Notes

- 1 Diegetic: existing or occurring within the world of a narrative rather than as something external to that world.
- 2 To see the test, go to <https://vimeo.com/720738209/ccb615ff0a>.
- 3 To see this test footage, please go to <https://vimeo.com/717562265>.
- 4 <https://tech.ebu.ch/tlci-2012>.

# Advantages and Disadvantages of Shooting in Virtual Production

## Advantages and Disadvantages of Using LED Volumes for Production

**Glenn Derry**

In early cinema, set extensions were filmed “in camera” with the use of painted backdrops, then trans-lights followed by front and rear projection techniques – which added motion and realism to the set extension illusion. With the invention of the optical printer came compositing matte paintings, and other photographic effects were made possible.

While compositing digitally generated set extensions is effective, there are drawbacks to an exclusively post-production-driven process. It can be difficult to create a unified vision when each part of the effect is segmented into departments and temporally siloed. LED volumes offer a return to an “in-camera” approach for set extensions.

An LED volume, in the context of this chapter, is the combination of an LED wall acting as a backdrop for a physical set, with a game engine producing projected renders for the display from the point of view of a physically tracked camera. There can be many shapes and sizes for a LED volume, from a simple flat plane screen, such as seen out an interior set window – to a full 360° wall surrounding the entire physical set with an LED ceiling. The unifying factor is the illusion of depth and 3D parallax, as seen from the vantage point of the camera.