Virtual production

a study on its environmental impact

FILM PARIS REGION

Green Screen
Interreg Europe

European Union
European Regional Development Fund

Table of Contents

1. What is the environmental impact of Virtual Production?

Introduction

Virtual Production (VP) is a new concept that has expanded rapidly during the last 2 years, growing as much in 2020 as it had been predicted to grow in a decade. The COVID crisis, which has notably constrained travel and made it much more difficult to shoot on location, was a key trigger to the virtual production growth. Valued at $1.6B in 2021, the Virtual Production market is expected to grow by almost 20% by 2030, with many advertisers and studios committed to moving 70% of their production pipeline to VP over the next two years (*Source : Virtual Production Market Size, Share & Trends Analysis, 2022 - 2030 by Grand Review Research*). All these companies are positioned on workflow proposals, sometimes providing the technical bricks of the rendering engines. Popular movies and TV series such as *Thor, Love and Thunder*, *Bullet Train*, *Game of Thrones*, *Star Trek: Discovery*, *The Last Kingdom*, *Black Mirror*, and *Outlander* have extensively implemented visual graphics to create epic and historical scenes.

Bringing cinema back in the studio after the French Nouvelle Vague got it out, Virtual Production mitigates some of the environmental costs of filmmaking by reducing transport and location fuel usage. But is it the panacea the industry hopes for? Or will the ecological costs of new sound stages and mass data transfer wipe out the potential gains?

Virtual Production is the latest step in cinema and TV technologies evolution that started with Georges Meliès and double exposure. Matte paintings, rear projections or green screens were used to shoot scenes that would have been impossible in real life. More recently, an interactive previsualization of 3D computer graphics environment was designed to help creative decisions for film makers, using a physical camera to move inside the virtual world with a live preview such as Jim Cameron's *Simulcam*, or being immersed using VR headsets in the case of Jon Favreau's *Lion King*. Television has also been using augmented reality technology where camera livestream is combined in real time with computer graphics to create interactive shows. *The Mandalorian*, which is widely considered to be the kick-starter for Virtual Production going mainstream, used a combination of all those technologies with large LED walls in order to create its environment.

This study aims to provide an overview of the environmental impact of Virtual Production while taking in consideration the technical, financial and artistic obligations of the field. We articulate the necessity of reducing significantly the industry's carbon emissions to be aligned with the Paris Agreements as the new geopolitical context will have a major impact over the way we produce content in Europe for the next couple of years.

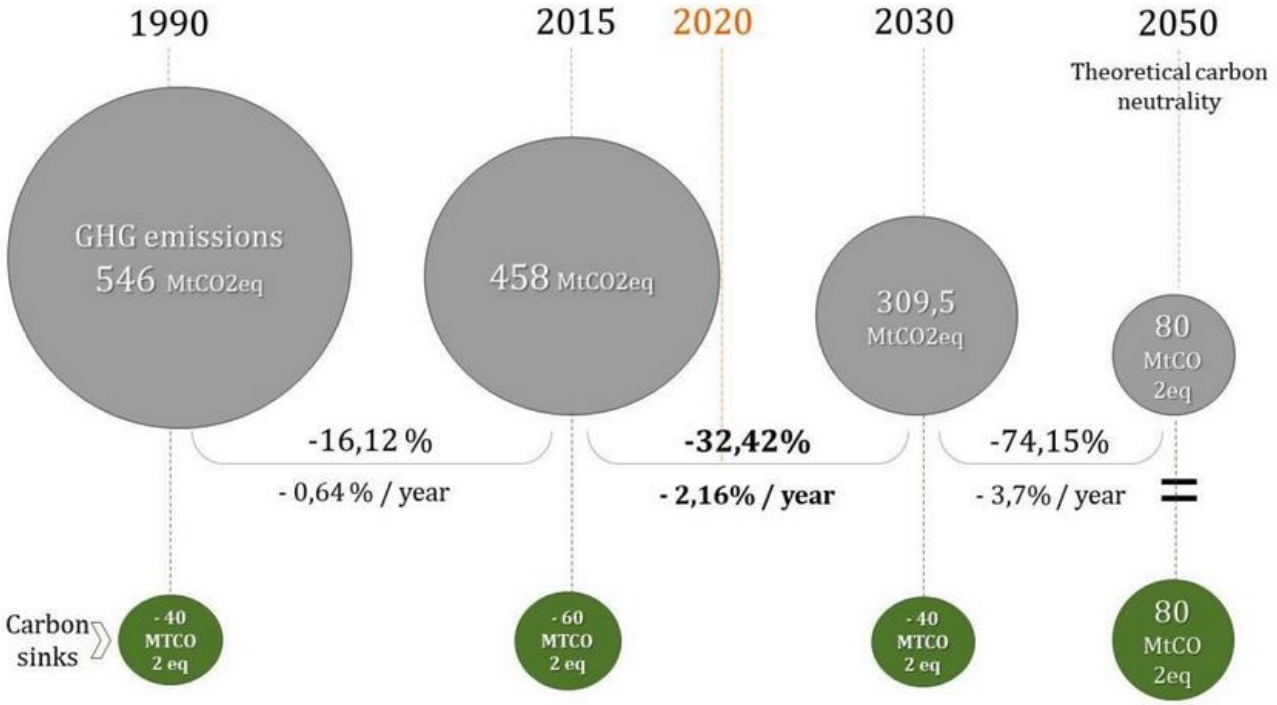
Environmental context

The environmental constraints that the media business faces can be translated into 4 components:

Climate

The aim of the Paris Agreement is to limit global warming to between + 1.5°C to +2°C maximum. To attain this, Europe has committed to reduce its carbon emissions by 55% by 2030 from 1990 levels. This means that greenhouse gas emissions that have not been reduced can be compensated by their absorption in greenhouse gas sinks (natural environment) as well as by harnessing, storing and

using the CO2 – the efficiency of which is still hypothetical. For example, in France, following the global greenhouse gas reduction trajectory which aims forcarbon neutrality, this means reducing emissions by 2.16% per year.



Source: Ecoprod study 2020: Reduction of GHG by 2050: SNBC AMS Scenario

Resources: critical materials and energy

Our planet is a finite world, and future availability of resources is a big question, both from a technical and geopolitical point of view. This will have an impact on the cost of resources used by the audio-visual sector and on its capability to sustain itself.

Over the last decade, the audio-visual sector has finalised the first phase of its digital transition. A second phase, whose key factor is the increased use of digital processes and the resources they require (cloud, 5G, LED walls), is emerging and – as we will see – those resources consume a lot of technical components and critical materials that are becoming subjects of conflicts between countries.

Energy is also a challenge: a major reason for current international movements comes from the fact that some countries have reached a peak in their production and must turn to other providers, which creates market tensions.

Production costs will increase proportionally to the direct consumption of energy and raw materials but will also depend on the purchase of goods and services – the manufacturers/suppliers of which will add the increased cost of resources to the price. It is not surprising that in the estimated cost of producing a fictional film for cinema release in 2019, it is those with a high proportion of energy and raw materials that will see increased costs *(Source: Albert)*:

▫ Shooting (31,1% of the budget)

- Technical (10,7%)
- Transport, reimbursement of costs, stage management (10%)
- Sets and costumes (9,4%)
- Overhead costs (5,7%).

Regulation

Fixing a target of - 95 % emissions of greenhouse gases by 2050 (compared to the 1990 level) to decarbonise the European economy will intensify European environmental regulations. The European Union is among the most dynamic economic powers in the fight against climate change. Indeed, in 2018, it had already reduced its emissions by 23 % compared to the 1990 level and its aim is to reach - 50 % by 2030. In December 2019, the European Commission presented its "Green Deal" for Europe, a set of measures designed to extend the goals for reducing greenhouse gas emissions even further by 2030 and 2050.

The aim of the Green Deal is to make Europe the first carbon-neutral continent by 2050, i.e. capable of balancing their greenhouse gas emissions with their absorption. Companies are continuously encouraged to choose green solutions and build reduction strategies. This encourages us to believe that in the near future, these incentives will disappear and be replaced by mandatory measures.

Market

Major media players have committed to net zero strategies such as the Science Based Target Initiative. This means that they will encourage their vendors and service providers to reduce their own emissions and at some point enforce double accountability, putting finance and carbon emissions in parallel when budgeting for acquiring or producing content. On an international scale some broadcasters recommend, or even impose, the sustainability measures of a production. This is the case in the USA with SVOD platforms; in Germany with the RTL group and especially in the United Kingdom with the BBC.

GHG emission scopes

Greenhouse Gas (GHG) emissions can be identified into different scopes.

Scope 1 emissions come from sources that are owned or controlled by the reporting entity. This could be the emissions that are directly created by manufacturing goods, for example, factory fumes. In the case of Virtual Production, this mainly concerns gas leaks from air conditioning systems. These are big contributors to global warming because of their strong greenhouse effect.

Scope 2 accounts for emissions generated by purchased electricity, steam, and heating/cooling. These emissions physically occur at the facility where electricity, steam, and cooling or heating are generated. As a user of the energy, the consuming party is still responsible for the GHG emissions that are being created.

Scope 3 emissions are emissions from sources that are not owned and not directly controlled by the reporting company. However, they are related to the company's activities. They are usually identified as generating from the supply chain of the company (vendors within the supply chain, outsourced activities, and employee travel and commute).

In many industries, Scope 3 emissions account for the biggest amount of GHG emissions. This is due to the fact that, in today's economy, many tasks are outsourced and few companies own the entire value chain of their products.

Positive and negative impacts of VP

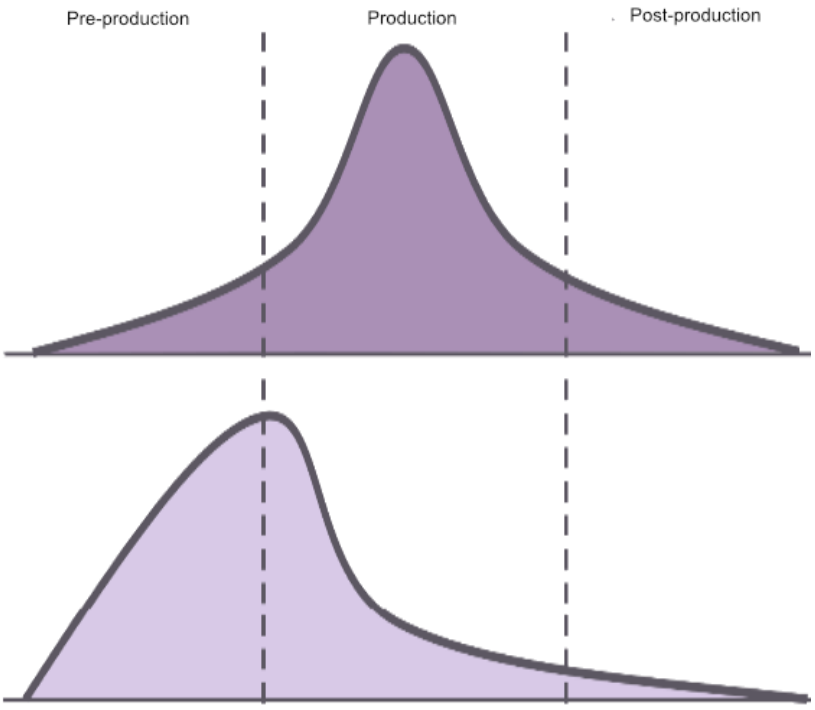


Fig: costs for traditional and virtual production (source Workflowers)

Reduction in transportation

According to Albert's Screen New Deal Report, travel and transportation of crew and equipment account for about 50% of the total emissions of a tentpole movie. By reducing the need to move from location to location, Virtual Production has a direct influence over an important parameter in production emissions.

This reduces the impact of:

- Vehicle emissions

- Crew catering and accommodation

Reduction in set building

While it does not eliminate completely the necessity of building props and elements of a scene, Virtual Sets do reduce significantly the volume of waste generated by shooting a production.
On average, a standard feature-length movie generates about 15 tons of waste (*Source: Film Paris Region, Circul'Art 2 Project*), which represents about 20% of the total emissions of production.

Naturally, VP reduces considerably the working time necessary to build scenes, which has a benefit both from a budget and carbon emissions perspective.

This reduces the impact of:

- Waste

- Crew catering and accommodation

Reduction in number of shooting days

There are several reasons why Virtual Production can reduce the shooting time:

Using a virtual environment, teams can transition from one scene to the next with very limited interruptions compared to traditional on location shooting. Digital assets can be changed quickly, allowing filmmakers to shoot several scenes with the same actors.

Also, in a virtual location, the filmmaker has full control over the weather, time of day, lighting, object position, and more. These conditions can be recreated at any time and are immediately available, saving a considerable amount of time. Some productions, interviewed for this study, have reported a significant reduction in shooting hours and size of teams, with a 20-25% reduction in work.days, but this is highly project dependent and should be validated by more research and production data analysis.

This reduces the impact of:

- Studio heating and cooling

- Equipment

- Crew catering and accommodation

Reduction in number of post-production days

A lot of the content that is created on a virtual set would otherwise have been produced with green screen shooting, which requires a lot of post-production work to remove the green cast and reflections on the images and then to recreate natural looking. While Virtual Production does not cover all the use cases of green screen shooting, it certainly has a very positive impact on the number of days of work to replace backgrounds.

The time dedicated to creating the assets used as a background would be almost equivalent between having them prepared for LED screens or for post-production. Experience shows that decision-making is easier and more efficient in the context of Virtual Production, especially if the DoP (director of photography), VFX supervisor and director are used to the environment and can interact during the Previs phase. This common vision accelerates the iterations and reduces the number of retakes. It is still difficult to evaluate whether extra work is required specifically for virtual production assets creation as the specificities are very new for most VFX artists.

Some productions, interviewed for this study, have reported a significant reduction in time of post-production and size of teams, with 10-30% reduction in shooting days, but this is highly project-dependent and should be validated by more research and production data analysis.

This reduces the impact of:

- Post-production facility heating and cooling

- Equipment

- Crew catering and accommodation

Overall productivity

A better vision over the complete project's art direction helps to reduce considerably the trial-and-error process: virtual production allows creatives to develop their vision earlier. This brings room for exploration by visualizing shots and environments before anyone steps foot on set, starting with low precision representations and building up. Iterating on their vision helps studios bring people together so that everyone can have a more complete understanding, from previs to post. Virtual cameras and green screen live-compositing act as a window into virtual worlds so contributors can see exactly what they are capturing. LED walls show filmmakers and actors what the set they are on looks like, both through their eyes and in-camera.

Rise in power consumption

Typical LED Panels used for Virtual Stages have an average power consumption just below 100W.and a Virtual Production LED project can assemble hundreds and even thousands of them depending on the volume needed.
They are also connected to a whole video and IT infrastructure that is comparable to a small TV stage added to a typical VFX post-production facility.

Increase of the manufacturing footprint

IT and video equipment have a considerable manufacturing footprint that is generally amortized after a short period of time.

It is also important to consider the IT components that are present in the cloud services. Though difficult to evaluate, they are not necessarily lighter on the emissions than their on-premise counterparts, since cloud services providers replicate the infrastructures over multiple datacentres to avoid service failure. There is nothing specific to Virtual Production compared to a typical VFX heavy production, but the use of remote workflows has made the use of cloud technologies more important over last couple of years. There are Sustainability in the Cloud working groups at EBU and SMPTE aimed at refining the values

Considering the positive and negative impacts, the equation to evaluate the impact of virtual production is a relatively complex one. The size of the setup has a direct effect on both its power consumption and its manufacturing footprint.

Rebound effect

Virtual production is, before anything else, a new creative tool for artists to deliver more exciting content. Whilst it helps save on financial and environmental costs compared to more traditional means of content production, it also offers opportunities to create more advanced productions for the same cost.
We must consider that the reduction of the environmental impact is a major topic and that Virtual Production might create a windfall effect. Communication today focuses on travel reduction, which is an important topic, but does not talk so much about the power consumption and manufacturing footprint of Virtual Studios.
A proper global strategy could only happen in a framework where carbon emissions are regulated and targets well defined, then Virtual Production can become a great tool to reach those targets.

Overview

The environmental impact of Virtual Production is currently difficult to fully evaluate, but we already have a good idea of the main impacts it has over a production's GHG emissions. Aside from an identified positive effect over important emission sources, such as travel and set building, it also consumes a lot of power and necessitates a lot of high technology equipment that has a big manufacturing footprint and are subject, at least for some, to rapid obsolescence. In the near future, we can expect some production data that will redefine or reorient the assumptions that are made today.

A very important point is integrating Virtual Production technology impact in Carbon Calculators. Indeed, the industry has developed several tools to measure the impact of productions, but the technology part is not fully defined yet: it is difficult to obtain information from manufacturers and the impacts for Cloud and IT infrastructures is extremely difficult to modeland calculate – both for technical complexity and lack of transparency reasons. As we include more and more digital technology in the production pipeline and this technology uses more and more energy and critical resources, we need to make sure we have the necessary precision in the calculation tools for productions to make the right decisions.

Using carbon calculators is important at different stages of a production: in the early days of budget preparation, for instance, it allows for a rough idea of the emissions of the project and compares it with average numbers for productions of the same genre. As the industry matures on this topic, production companies will better understand where they can reduce their impact. This is becoming important as organisations that finance or subsidize projects evaluate them on their environmental impact. For example, the European Media Project has set more points on environmental parameters in the evaluation of project submissions and the CNC will ask productions to calculate their carbon emissions starting in 2023.

Broadcasters and streaming platform are also more and more aware of the GHG emissions topic, and some, especially in Europe, have committed to the Science Based Target initiative and are asking the production companies they work with to calculate their carbon emissions. The BBC for example requires an Albert certification for content commissioned for TV Broadcast.

Finally, as we will see in the Studio Impact section, all virtual stages are not made in the same way and there is a market offer adaptation to the real needs of production. This market is in evolution and shows that there is room for innovation in services and equipment. Better integration with post-production will also have a positive effect on the overall efficiency, from both GHG and budget perspectives.

2. GHG impact of a production

Protocol

In this study we have decided to focus on the equipment used to shoot a Virtual Production project and compare it with a more traditional green screen shot project of comparable size and quality. We use the data from a recent article published by the Filmakademie Baden-Württemberg Animation Institute. For the GHG impact calculation we use a set of data described in the GHG Assessment data section of the bibliography.

We used the Open Media Workflow Modelisation methodology, an open-source bottom-up approach developed by Workflowers that has been used to determine some emission factors in the **Eureca** European Carbon Calculator for Media and will also be implemented in the new version of **Carbon Clap**, Ecoprod's carbon calculator for media production. To determine the impact of a production, we examine each step of the workflow and determine the resources used

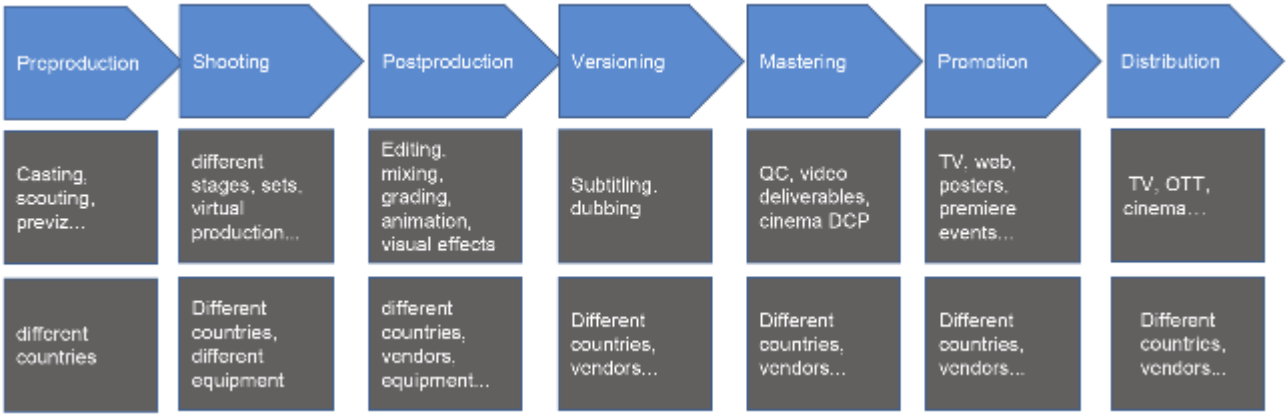


Fig : Workflow steps in linear content production

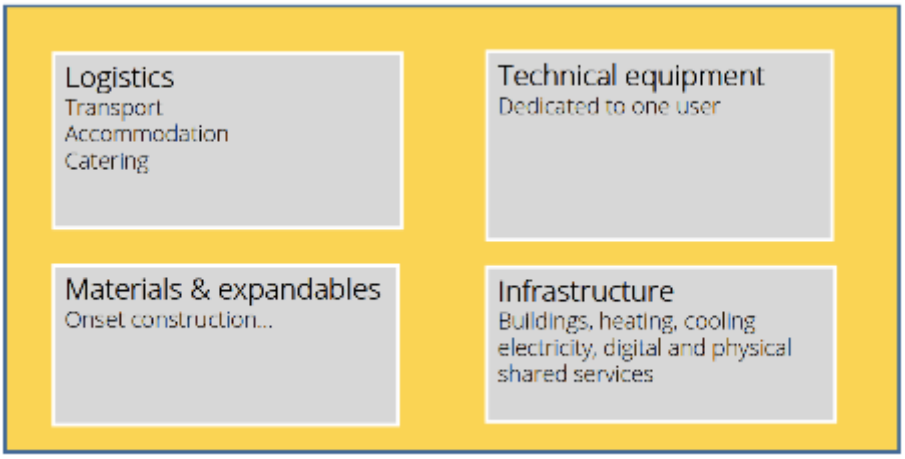


Fig: Elements considered for carbon emissions calculation

Energy Consumption

The Filmakademie Baden-Württemberg Animation Institute has performed a test published as a Siggraph 2022 paper comparing a full green screen movie production and an equivalent project produced in a Virtual Production environment. This study focuses on energy consumption of the equipment used in both situations.

	Sprout (Offline)		Awakening (Virtual Production)	
Production days in studio	2 days		2 days	
Final frames with VFX	3233 frames		8898 frames	
Pre-production	100 person days	213 kWh	175 person days	588 kWh
Post-production	300 person days	638 kWh	150 person days	504 kWh
Displays (Pre and Post-prod.)	400 person days	190 kWh	325 person days	155 kWh
Offline Rendering		4032 kWh		27 kWh
LED wall				299 kWh
Real-time Rendering				22 kWh
		5073 kWh		**1594 kWh**

*Fig: compared power consumption of the 2 productions (*Source: https://animationsinstitut.de/en/research/publications)

This project is a comparison between two student short movies, “Sprout” (“Offline” in following descriptions), a VFX intensive movie shot with a traditional green screen shooting approach, and “Awakening” (“VP” in following descriptions), a project with a comparable artistic ambition shot using a LED wall. It is interesting to see that on “Sprout”, 25% of the effort was set on pre-production and 75% in post-production, while on the “Awakening” project 54% was allocated to pre-production while 47% went to post-production, with an overall 19% less work duration for almost 2.8 times more final pictures produced.

The “Awakening” (VP) project would certainly match in constraints a sequence in a professional long form movie or TV series: apart from the very short shooting time, the duration of tasks is comparable to professional productions as experienced by Workflowers team. The assumptions that have been made on render times are also a valid starting point considering the variability of VFX production workflows.

The carbon emissions for the whole production using the electricity carbon intensity of the countries involved in Green Screen, would be, in kgCO2e (keeping in mind that those countries have different sources of energy, I.e. France’s use of nuclear energy keeps its CO2 emissions quite low):

kgCO2e	Offline	VP
Belgium	1116.06	350.68
France	288.65	90.70
Poland	3962.01	1244.91
Romania	2531.43	795.41
Spain	1207.37	379.37
Slovakia	999.38	314.02
Sweden	152.19	47.82
UK	1075.48	337.93

Fig : carbon impact of production / total electricity consumption

Indirect emissions

Most of the equipment used in Virtual Production is manufactured in Asia, such as the LED tiles that mostly come from Shenzhen in South China; and this equipment incorporates many critical materials. If we look at a typical LED tile used in a cinema studio configuration such as the Roe Black Pearl tile which weighs 9.35 kg, it means that on a large 2000 tiles volume we have 18.7 tons of equipment just for the tiles. The structure to which they are attached needs to be 2 to 3 times heavier than the tiles depending on the configuration.

Thus, it is necessary to keep in mind that LED panel manufacturing is a complex industrial process which uses a lot of critical and toxic materials which therefore will have a significant environmental impact.

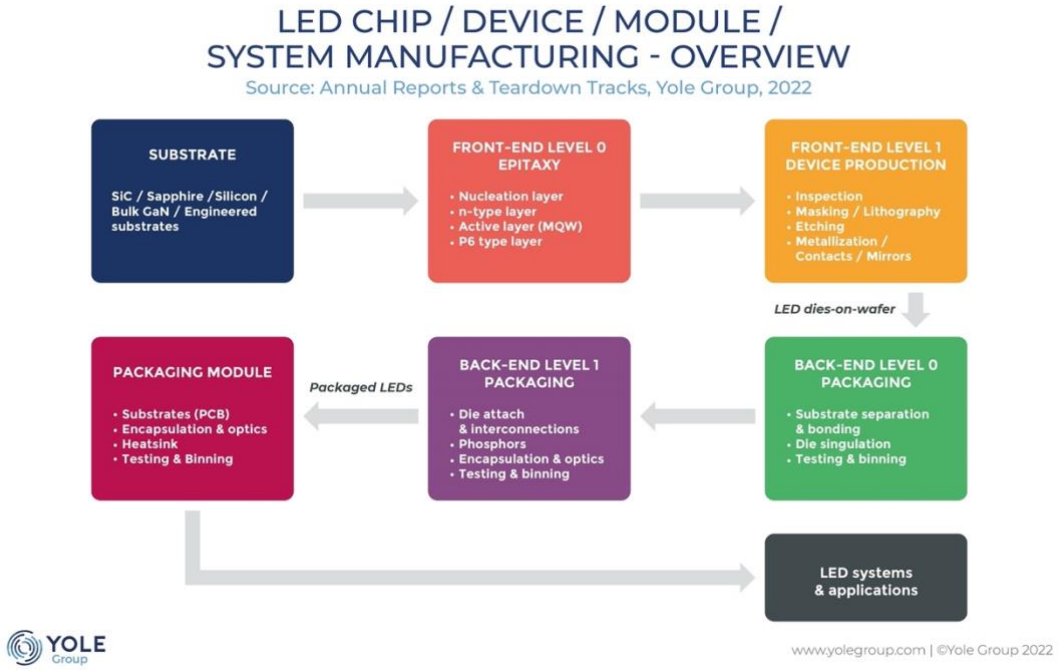


Image courtesy of Yole Group, 2022

At the time of this study, no Lifecycle Assessment (LCA) of LED tiles was available to evaluate the carbon impact of LED tiles and manufacturers were unable (or unwilling) to provide the information.

If we take technological display-centric equipment, such as televisions, tablets, mobile phones, laptops, cradle-to-gate impact [1] (ranges between 31 kgCO2e/kg (40-49' television) and 70 kg/CO2e/kg (mobile phone). Making an assumption of a 40 kgCO2e/kg impact for an LED tile is probably conservative considering the manufacturing process and material use but it is a good starting point. What we find to be a positive aspect is that LED tiles seem to have a long life cycle and it is easy to re-purpose them for secondary usages, so we can consider their usage to be amortised over 10 years.

If we consider the 4x10m wall used at the Filmakademie made of LEDitgo tiles that are 500mmx500mm and 11,8kg each: that is a total of 160 tiles and 1888kg, which means 75,52 tCO2e and 20.69kg/day. We are not considering here the metal structure to hold them, which could be between 4 and 5 tons, but its impact is much lower as it can last a long time and is easily recyclable.

IT equipment is also known to have a considerable impact as the overall GHG emissions of the sector represent 4% of the global world emissions, and they continue to grow at a fast pace.

Regarding the workstations, the French ADEME database considers a high-performance PC to have a 169 kgCO2e cradle-to-gate carbon impact (for machines that will last an average of 6 years (production data, Workflowers)) and a 239 kgCO2e impact for a 23.8' monitor. Considering CG (computer graphics) and VFX artists usually use two monitors, we have a total of a 647 kgCO2e impact, which means a manufacturing impact of 0.295 kgCO2e/day.

A typical Virtual Studio environment will have IT and video infrastructure which is comparable to the one in a VFX post-house managing projects the same size. It also has the equipment of a small TV stage, with video servers, mixers and cameras. Since we did not have that specific information in the Filmakademie study, it was not included in the calculation, but it could be considered marginal in the overall calculation. Another value that was not captured is the power consumption of lighting for the Sprout project. Here we have the impact of the manufacturing of the equipment considered for the production time for the "Sprout" (Offline, traditional green screen shooting) and the "Awakening" (VP) project:

kgCO2e	Offline	VP
Workstations	118.17	96.02
LED Wall		41.38
TOTAL	**118.17**	**137.40**

Fig : calculation of the manufacturing impact of equipment (kgCO2e)

What is interesting is that the manufacturing impact of the equipment used on "Awakening" is larger because of the big contribution from the LED wall. If we add it to the carbon impact of electricity consumption we obtain:

[1] Cradle-to-gate is an assessment of a *partial* product life cycle from resource extraction (*cradle*) to the factory gate (ie, before it is transported to the consumer)

kgCO2e	Offline	VP
Belgium	1234.23	488.08
France	406.82	228.10
Poland	4080.18	1382.31
Romania	2649.60	932.81
Spain	1325.54	516.77
Slovakia	1117.55	451.42
Sweden	270.36	185.22
UK	1193.65	475.33

Fig : calculation of manufacturing impact of equipment (kgCO2e)

If we take the countries with the least and most carbon intensive electricity mix:

- making “Sprout” in Sweden would have emitted 270 kgCO2e while making “Awakening” would have emitted 185 kgCO2e
- making “Sprout” in Poland would have emitted 4.08 tCO2e while making “Awakening” would have emitted 1.38 tCO2e

The values are very different and show that the energy that is used in those countries has a considerable impact over the carbon impact of a production.

Let us figure out now what would be the compared impact per day, including manufacturing impact, for an LED wall, a large volume, a workstation and a render server (Same manufacturing impact as a workstation without monitors, 500W power consumption, running 22h/day)

impact/day	40m2 Wall	1m2 Wall	400m2 volume	Workstation	render
Belgium	53.58	1.34	535.80	0.87	2.50
France	29.20	0.73	291.97	0.44	0.70
Poland	137.45	3.44	1374.50	2.33	8.67
Romania	95.29	2.38	952.91	1.59	5.57
Spain	56.27	1.41	562.71	0.91	2.70
Slovakia	50.14	1.25	501.42	0.81	2.24
Sweden	25.18	0.63	251.75	0.37	0.41
UK	52.38	1.31	523.84	0.85	2.41

Fig : impact of different equipments per day (in kgCO2e/day)

This chart gives us some ideas of the compared impact between different pieces of equipment: in Spain, a 40m2 LED wall emits 56.27 kgCO2e per day, while a workstation emits 0.91 kgCO2e. This approach is incomplete as in a proper Scope 3 evaluation we would need to also compare the impact of travel, freight, commute and food for the crew and VFX people. However, in this case, that information is not necessarily relevant to what we are trying to observe.

A key element in the reflection about Virtual Production is making sure that the stage and the walls are the right size, as well as potentially mobile in order to reduce travels and save days of shooting. The number of days spent on a virtual set has a big carbon impact both from a manufacturing and power consumption point of view, but also from a financial perspective. A LED setup three or four times bigger, one or two extra days of shooting or post-production would have completely changed the result.

If we look now at the compared impact of one day of 400m2 LED volume, from a purely technical standpoint, without technicians operating it, without the technical infrastructure, without the studio impact, but with a VFX artist impact, considering 1.84kWh per day for the impact of 5m2 of office (Source Observatoire de l'Immobilier Durable), 2.64kgCO2e/day for the food and 2.11kgCO2e/day for the commute from home to office (statistical data established by Workflowers based on ADEME statistics and emission factors), we can compare the number of days of VFX work it takes to match that impact:

impact/day	400m2 volume	VFX artist	nb of days
Belgium	535.80	6.00	89
France	291.97	4.85	60
Poland	1374.50	6.19	222
Romania	952.91	5.67	168
Spain	562.71	5.19	108
Slovakia	501.42	5.11	98
Sweden	251.75	4.81	52
UK	523.84	5.14	102

Fig : compared CO2 impact of LED volume and VFX artist (in kgCO2e/day)

This means that, regarding CO2 emissions, the impact of a day of shooting on a 400m2 volume in Belgium is equivalent to 89 days of work for a VFX artist, and 168 days in Romania. That shows how much dimensioning is important and that we should calculate the impact before the production to make proper decisions.

To summarize, the emissions of Virtual Production depend on a lot of technical and production parameters. The electricity mix of the country also has a major impact as we are talking about equipment that have a big electric power consumption. Larger volumes would be used mostly for big, well-planned projects and would be directly connected to multi-service studios capable of providing the production with a complete offer to optimize the time spent on expensive, resource heavy and power-hungry LED walls. Once again, planning is the key to reduce carbon emissions.

Another consideration for the Scope 3 impact of equipment is the fact that a lot of devices are also evolving at a very fast pace: as some of the technology is in its early stages of maturity (at least in this particular use), innovation is strong and renewal cycles are quite short. This is also true for graphic workstations and particularly graphic boards that are constantly evolving to get the benefits of latest software enhancements. As we have seen in both the gaming industry and animation/VFX communities, software updates can significantly reduce the lifetime of hardware: new version of tools require new graphics board and newer programming libraries that run only on latest CPUs.

Gathering data

The VP Green project driven by the University of Greenwich is collecting production data to evaluate the difference that Virtual Production is making on the production of GHG emissions. As it is still a fresh topic, a lot of productions are still experimenting, crews are learning, and errors are made and fixed. We will probably see the evolution in time.
If we look at the perimeter of Virtual Production, we should consider that not all movies are ready for VP. In France according to the CNC, only movies above a 15 M euros budget have a significant part of it for VFX – about 12%, compared to a 2.6% average. As Virtual Production does have positive impacts on budgets and GHG emissions, we can imagine this number raising a bit, but the cost of Virtual Sets and associated workforce will stay high and unaffordable for a lot of productions, until it makes sense for a sequence of the movie.

We must keep in mind that VP will not be used for a complete movie in most cases: apart from large VFX-intensive productions, only some with sequences that benefit a lot from VP techniques will be shot this way.

3. GHG impact of Virtual Sets

Market Overview

There are approximately 120 production size LED stages as of today with a majority in North America and Northern Europe, with a fast expansion in Asia. Universities and film schools also invest massively in the technology, encouraged by the programs from manufacturers and software editors. Most have been installed after 2020 and after *The Mandalorian* was released and largely promoted in the medias.

There has been a strong acceleration in this phenomenon due to the Covid restrictions, with stages popping LED walls that were not used on the live event market. They were used for TV shows, commercials and fiction productions. In Europe, the AV industry is in the process of building its infrastructure, as evidenced by the fact that 32 applications out of 122 at the CNC Recovery Fund (France, “Shock of Modernization”) were related to Virtual Production. About 12 movies or TV series have used VP techniques in France between 2020 and 2022, which shows a strong adoption rate. It has also been used extensively on commercials. Major productions that would have been shot in real-world locations or on green screens suddenly were reconfigured to be partially or entirely shot on LED volumes instead. These include *Star Trek: Discovery*, *Thor: Love and Thunder*, and *Bullet Train*.

In 2020, there were less than ten operational platforms in the world. After the United States, particularly in Los Angeles, and England, sound stages in the studios of Prague and Budapest, as well as in France, Spain, Germany and the rest of the UK are currently being equipped.

Hollywood studios such as Warner have installed Virtual Production facilities in some of their production studios across the world, as some big VFX companies with facilities in different countries partner with large sound stage providers to provide integrated services between Virtual Art Deparment, LED stages and post-production.

This list of companies providing VP services shows the diversity in approaches, which is logical as it matches the vast diversity in content production. We can identify 3 main profiles:

Large facilities with permanent installations with more or less flexibility that make sense for large projects. It is about making sure the production gets all the required services in a fluid workflow. Managed by big companies working for big studios, partnering with other companies to cover Virtual Art Department, Previs, Shooting supervision and VFX. In general, the virtual set is managed within a partnership of international companies (VFX companies, rental companies or film studios).

Smaller facilities with permanent installations that fit small projects, commercials, car shots, music videos. They also usually partner with VFX companies to provide a good continuity of services.

Consulting and rental companies that go with mobile equipment on the sound stage the production has picked, so they build a bespoke setup with the right size and configuration for the project.

As the market matures, we may see other value propositions emerge and current vendors adapt their offer. At the moment, larger facilities tend to evolve towards more modular offers, as the cost of a 2000+ LED tiles facility – that can amount to more than 20 M euros – makes it very expensive for

productions. It is also important to notice that it is possible to work on some projects with live compositing of green screen, as it has been done in TV for a long time, without LED walls.

Case Study: Dark Matters

https://www.darkmatters.one/

Dark Matters is a studio founded in 2021 by a team of international experts in the South of Paris. The concept is a one-stop shop, designed to provide all services from Virtual Art Department, Previs, Shooting supervision, Motion Capture and In Camera Effects. The studio is a large facility in Essonne, 45min drive from Paris, with six large sound stages, offices and workshops over 12.000 sq meters of indoor facilities to allow multiple teams shooting or preparing at the same time.

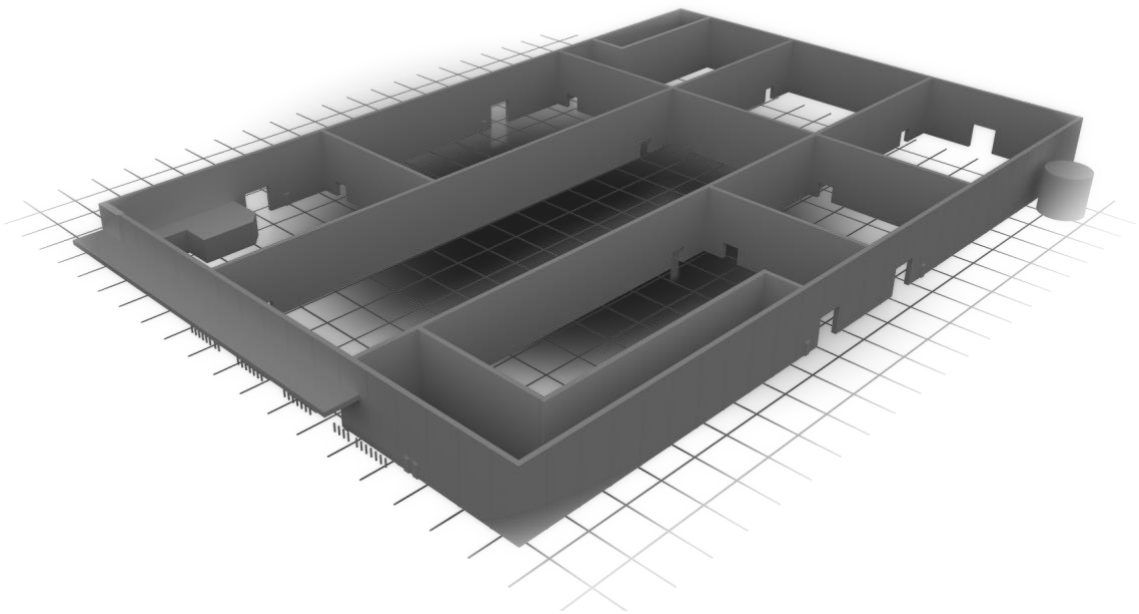


Image courtesy of Dark Matters

The Virtual Art Department creates the content for the walls and can start from Previs and provide full continuity for the creative team to finalize all the assets for shooting.

Dark Matters also provides motion capture services with a large volume that allows for real-time capture of movements of people, animal and objects but also for Simulcam Previs setup so the creative team can interact with the digital world in real time and prepare the shooting and camera settings.

Equipment
The IT infrastructure is equivalent to a mid-size visual effects facility:

- 4 storage servers for a total of 700 TB of online capacity

- 25GB network backbone for server communication and 10GB for workstations.

The total power consumption of the IT infrastructure is about 12kW at full charge.

Based on data acquired from ADEME, we can consider that the cradle-to-gate (manufacturing processes and transport of equipment to user) carbon impact of this equipment is 34.70tCO2e, with a usage impact of 16,39kgCO2e per day.

The total number of graphic workstations is 30, with 8 more at the “brain bar”, where the technicians operate the walls on the stage when at full capacity. Each workstation has 2 monitors, which makes a total of 24,59tCO2e for their manufacturing impact.

Dark Matters designed some custom mobile structures that allow for a lot of flexibility, as they can move modules to configure LED volumes on small or large stages, to fit the precise requirements of the production. The modular approach allows for a good compromise between permanent structures that do not require setup time but are not perfectly matched to the production needs and *ad hoc* setup that takes time to install and configure.

Each of the five configurable panels is 5x6m, which is 120 LED tiles, weighing 1.2t while the structure to hold the tiles weighs 1.4t. The total power for a LED wall module is 11.4kW average with peaks up to 22.8kW. Based on the assumptions taken for the production impact, for each LED wall module, the total carbon impact represents:

- 45.12 tCO2e for its manufacturing footprint
- 7.78kgCO2e for one day of operation (12h, French Electricity mix)

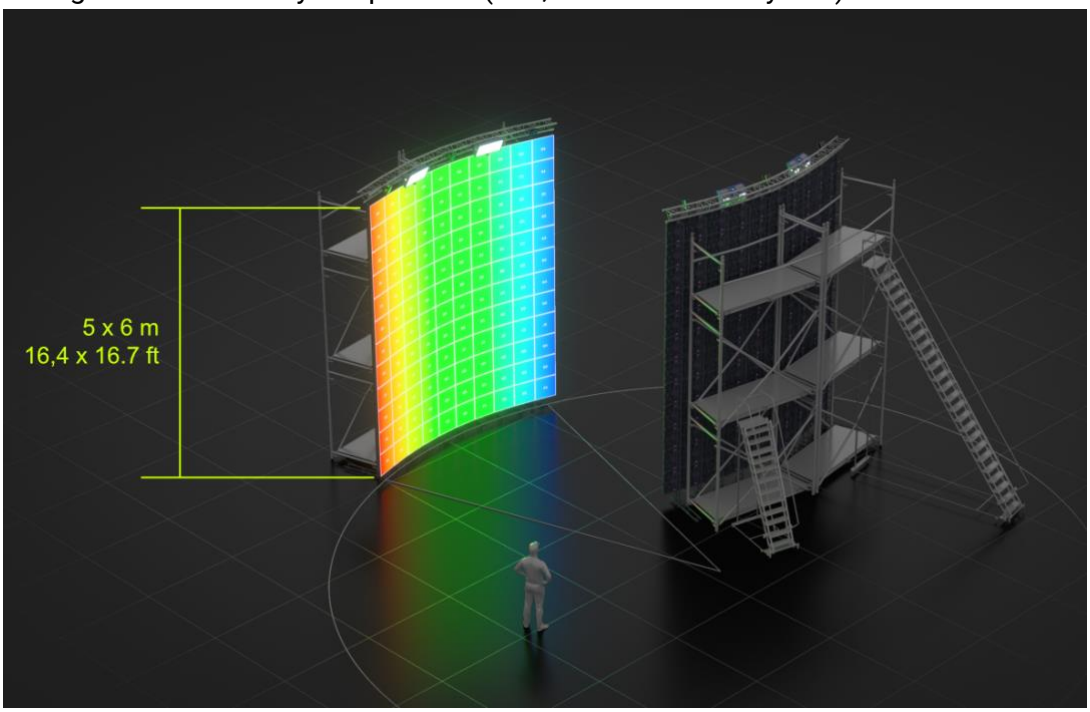


Image courtesy of Dark Matters

Each module is connected to a rack with video renderers and distribution which weights 184 kg and consumes 2200W, which represent a 14.85tCO2e for the manufacturing and 1.50kgCO2e per day of operation (12h, French Electricity Mix). The total manufacturing impact of LED panel + rack is 59.97tC02, with 13.6kW of average consumption.

Those are overall large numbers that go with the size of the studio, though the low carbon emissions of French electricity mix is certainly an advantage. The service is designed for demanding productions asking top technology and service.

Image courtesy of Dark Matters

The studio was designed with sustainability in mind: the site has hotels and accommodations close so the crew does not have to travel much, and the studio is large enough so the whole production can be shot on site with minimal movement from people and equipment, saving time, energy and money. The stages were built with extra insulation that is good for both thermal and sonic performance. More importantly, the modular structures are enabled only when needed, so there is only power consumption for the necessary equipment.

Case Study: Neoset

https://www.neoset.net/

Neoset took a very different approach: the company does not own a single LED tile; it works with rental companies and a group of experts to bring Virtual Production to the shooting stages anywhere.

It was founded by camera rig and technology experts that know the production environment very well. They fine tune the setup in advance with the production team and bring the equipment and

team to operate it. They have been working on a lot of different projects from music videos and luxury events advertising to TV series. They partner with a VFX company that knows their workflow well and can connect very efficiently with their productions.

Neoset also develops software tools to have more flexible control of the playback of sources and ease the connection with other devices.

The carbon impact of their setup in production is lighter in operations but there is an added impact caused by transportation, longer setup and wrap time. As they use equipment from rental companies, the equipment used may be used more often and more efficiently than on a permanent setup, but there is no data to confirm this hypothesis.

There is no specific environmental approach in the concept developed by Neoset but its agility and lean approach certainly helps to attain a form of sobriety and avoid rebound effects.

4. Potential improvements

GHG emission measurements

The state of play regarding LED technology's GHG impact measurement is poor. As of yet manufacturers do not publish the Lifecycle Assessment of their products and, as it is an important parameter in the equation, we are missing a crucial part of the information. Measuring power consumption is easy, so this should be a point of attention.

We can hope that in the near future, encouraged by increased environmental awareness, equipment manufacturers will deliver precise environmental impact figures for their products so we can have a more refined calculation and make it easier for productions to choose a solution or another.

The potential of automation

The time to prepare assets and scenes could be significantly reduced with the latest advancements in technologies such as procedural asset generation and AI.

Procedural techniques mean that an algorithm generates components of a scene based on an equation, an algorithm, so the artist has a set of controls to generate infinite variations of building models to fill cities, clouds to fill the sky, rocks to fill the desert.

Procedural asset creation is already massively used in video games to generate different components such as levels, maps, music, lighting, animations, etc. It is also used in CG animation and VFX for some parts of the process, for example crowd simulation in battle scenes.

Procedural animation in the context of a game engine is a natural plug and the opportunity of a VP environment allows to better connect the concept to a production, especially during the previs stage, and have continuity of data along. While on a virtual set, certain behaviours can be connected to sensors so the animation can be affected in real-time by the actors playing or the camera movements.

For example, some tools allow to generate buildings out of a few parameters

Artificial Intelligence (AI) has the potential to bring automation in the creative process to another level. From concept art to automatic animation, it will have a significant impact over the workforce and infrastructure necessary to produce content.

As opposed to procedural techniques, AI algorithms "learn" from massive libraries of examples, for instance it connects representations such as pictures or sounds with words so when you type a word the algorithm has detected common traits between the representations, which generates the logic driving the **procedural generation** of content.
Big technology companies such as OpenAI, Google and Nvidia invest massively in AI technologies, connected at different points in the creative process.

OpenAI has developed DallE, a tool that inverts the process of image description, so it can generate an image based on text.

Nvidia has also developed a set of tools to generate content from AI algorithms.
GauGAN : Photorealistic image from simple drawing or text
GauGAN360: Photorealistic 360 panorama from brush input

Google developed PARTI, a similar text-to-picture generator.

Industry software editors Autodesk, The Foundry or SideFX are integrating machine-learning based tools to accelerate the editing and generation of content.

All those technologies evolve quickly, so we can expect major breakthroughs in the capacity to generate digital content fast. It is important though to remember that AI itself has a considerable environmental impact as it requires massive volumes of computation on high-density hardware to train the models.

Asset management

Creating assets for the digital environment is a big task that can take a considerable amount of time and resources. For some technical reasons listed below, visual companies have, ever and ever, been recreating the same assets:

- Evolution of software tools used for creation, including scripts and plugins, that jeopardizes the compatibility file formats
- Evolution in the quality and precision requirements
- Lack of time and resource to manage properly data flow and archives
- Lack of proper technology to manage this issue

For the latter point, an industry-led initiative was undertaken the last couple of years to address it.

SAUCE was a three-year EU Research and Innovation project (January 2018 – December 2020) between Universitat Pompeu Fabra, Foundry, DNEG, Brno University of Technology, Filmakademie Baden-Württemberg, Saarland University, Trinity College Dublin, Disney Research to create a step-change in allowing creative industry companies to re-use existing digital assets for future productions. Within the framework of that project DNEG produced a number of documents about a semantic approach to the problem.

Movielabs, the Hollywood studios' common R&D entity, launched an accelerator project at IBC 2020 that exposed some of the difficulties for Asset Management solution providers to integrate CG assets.

More recently, The Foundry launched the OpenAssetIO Open Source Project within the ASWF framework, following OpenColorIO and OpenImageIO and OpenTimelineIO projects aimed at standardizing processes across industry tools and vendors.

Standardization of digital asset formats

The industry is pushing through multiple initiatives such as the Academy Software Foundation (www.aswf.io), which works towards the standardization of processes and file formats to ease the interoperability between systems. Also, new CG technologies such as USD and ILM Material X make it easier to create CG assets that can be reused in different creative tools, render engines and environments. Those are open formats that can be read by most systems, supported by the open-source community.

This does not only provide easier ways to communicate between tools and facilities, it also creates a framework for companies to create massive libraries of reusable content and makes it easier to monetize assets.

Asset monetization

Another approach based on proprietary formats is the one coming from Unreal, which provides a library of scans (Megascans) directly integrated in the Unreal Engine with a lot of free content available, but also paying content. It makes the creation of a scene extremely efficient by dragging and dropping a lot of elements, or even allows to complete scenes into the digital set and adjust them to your taste.

There is already a considerable market for stock footage and CG assets, and a marketplace where digital artists can monetize their creations. There are even specialized websites to buy CG clothes.

We can expect that at some point a lot of the content displayed in the LED walls will be coming largely from libraries assembled by artists in a much more efficient way than it is today. This has a considerable impact on the emissions of a production as it can reduce massively the number of days necessary to create the digital environment if assets can be easily re-used, shared and edited.

However, we must realize that this process will generate copyright issues. Indeed, productions and VFX vendors must agree on the property of the created assets, and copyright will most definitely be an issue for famous places or landmarks such as Notre-Dame de Paris.

Training

In order to embrace Virtual Production, a major challenge for the industry is to get enough technicians. As there is already tension on the market today to recruit artists and engineers for animation and VFX, getting talents to operate virtual sets will also be challenging if everybody is looking for the same kind of profiles.

On their production blog, Netflix describes a list of jobs involved in the operations of a Virtual Production.

ROLE	RESPONSIBILITIES
Director of Photography	Critical to approve/lock in looks, more than on a traditional shoot, as the LEDs provide both lighting and what is being captured through the lens.
Editorial	Makes plate selects prior to the shoot and to assemble previs/techvis animatic for the Media Server Operator and additional crew so that they understand the number of setups and camera angles required.
Production Supervisor	Connects additional personnel for essential conversations and coordinates additional/alternative logistics (ie. connecting Transportation with LED Technician to understand what the layout of the walls will be, and figure out how to load in cars...)
Production Designer	Understands the scope of set build required — what will be practical, and what will be displayed on the wall. Can help hide the blend where stage meets the bottom of the wall, through set design.
Gaffer	Assumes the responsibility of LED panel oversight and plays a critical role in ensuring safety and functionality with other lighting elements.
VFX Supervisor	If there are plans to incorporate VFX into display content, or onto plates in Post, it is imperative to have the VFX Supervisor involved in the pre-production process and on-set to avoid costly redos down the line.
Post Supervisor	Works with the Director/DP/Editorial to make plate selects for each scene, ensuring that they are up to spec according to the Virtual Production Supervisor and Media Server Operator.
DIT	Plays a crucial role in linking the creative look with the technical appearance of the LED panels. Helpful in identifying issues and can often aid with signal chain issues as well.
Virtual Production Supervisor	A new and emerging role, it is similar to a VFX Supervisor and serves as the informed captain for all of the moving parts within the Virtual Production pipeline, ensuring that all infrastructure, teams, and phases of production are moving according to plan from prep through shoot. Works closely with the VFX, Post Supervisor and Production leads to ensure alignment throughout.
Media Server Operator (or 'Engine Operator' in 3D)	A new role that is responsible for the ingestion and operation of content on set and stages content according to shoot schedule. Also operates the display of content and positions/adjusts plates on the display, ultimately playing/resetting footage as needed. Depending on the infrastructure and scope of the shoot, two operators may be needed.
LED Technician (or 'LED Engineer')	A new position in charge of the physical set up, movement, adjustment, and tear down of LED wall infrastructure. Also necessary to have them on set during the

	shoot in case of any troubleshooting needs with the LED panels.

Source: https://partnerhelp.netflixstudios.com/hc/en-us/articles/1500002237121-Production-Context#h_01F3BAW0X8PCBSGNGZB00RW0CM

For most, training will be about adding some new skills to their current job so they can better integrate VP concepts. It is also important to notice that not all people working on traditional workflows will be able or willing to transition to a digital intensive world: as VP is connecting the digital and physical world, it will take some time for software and hardware products such as dollies, robot arms, to be fully integrated between the two worlds. In the meantime, it will take engineers to write scripts and code to glue things together.

There are industry initiatives in place to get technicians and artists on-board with curated information. The Society of Motion Picture Technicians and Engineers has launched a Rapid Industry Solution program with the On-Set Virtual Production Initiative, where people share experience and progress while working on common language and description of the different steps and requirements of Virtual Production.

Software and hardware vendors also provide online training content for their tools and partner with universities and some VP service providers to propose training sessions on actual virtual sets.
Netflix has been encouraging productions to experiment with Virtual Production and has a helpful section on its online wiki.

Some companies have developed online and onsite training services, with certifications on different configurations. Check for some links in the “Learning Virtual Production” section of the Bibliography.

5. VP in a world of shortage

An important aspect of sustainability is the capability to adapt your business in a world that changes. The current geopolitical situation is accelerating the supply chain disruption on energy and key hardware components.

Power

Large VP facilities must provision important power capacity to feed the set and infrastructure. In a world where electricity will be more and more prone to cuts and disruptions those facilities will have to rely more and more on power generators, which have a disastrous carbon impact. Having the capability to run modules independently would be a good idea, as smaller setups will be much more resilient. Current battery technologies cannot provide the solution for the power levels required to operate a large size virtual set. We must note that this problem will affect all sound stages and not specifically virtual sets.

Equipment availability

As a lot of the technological components of Virtual Production are manufactured in China and Southeast Asia and don’t have easily swappable alternatives, the geopolitical situation may disrupt for a period of time the supply of necessary hardware. This is a situation that we have already seen during the Covid crisis with the supply chain for graphics cards and LED tiles disrupted.

Conclusion

Are Virtual Production techniques applicable to any movie? Yes. Does this mean that every production will use them? No. However, in a world of increased worry and attention towards our environmental impact on the planet, all aspects of the audiovisual sector must come into scrutiny and if Virtual Production is going to be used as a “sustainable solution”, we must be able to know what impact it truly has.

With its small, mobile setups, Virtual Production can significantly reduce production and also save a lot of time on-set and on travels; even, in some situations, allow to work with a smaller crew. Experience over the last two years shows considerable savings of 10 to 30% on shooting time. It also allows for a much more interactive creative process, resulting on better efficiency in the creation of the digital environment.

Though the environmental equation of Virtual Production is a complex one, we must remember to consider the power consumption and manufacturing footprint. VP can certainly bring large benefits to a production if it is well planned and operated. It can also have a terrible impact if not well managed, especially because of its electricity consumption – and the energy source for this electricity should be considered a critical point. Energy consumption remains a main concern as we can expect power shortages in Europe over different periods of time and having high power requirements means that it may be difficult to operate studios at certain times of the year.

Based on what has been observed, productions should establish a carbon budget to evaluate the environmental benefit of VP to their project but must remain careful about a potential rebound effect. Also, a proper regulation of carbon emissions for the sector is necessary if we do not want to see them go out of control. Moreover, having an accurate measurement of carbon emissions is extremely important and we are still missing important data, such as the LED tiles manufacturing footprint, which prevents us from making precise calculations. Once the data is available, it is also important to get it integrated into the industry’s carbon calculators.

As the ecosystem is shaping itself with leaner and more mobile solutions to adapt to the production needs, flexibility is the key. Also, training the technicians and production teams so they can make the most out of VP technologies, and better integrate the VP budget into the VFX budget, is the best way to anticipate environmental issues.

In conclusion, Virtual Production is another creative tool brought to the creative community palette, like so many in the history of cinema and media. It is by being as efficient as possible, in all aspects mentioned above in the study, that we will succeed in making VP a truly viable sustainable solution to the environmental issues the audiovisual sector faces.

Appendix

A. List of acronyms and abbreviations

AI: Artificial Intelligence
AR: Augmented reality
CG: Computer Graphics
DCC digital content creation
DIT : Digital imaging Technician
DoP : Director of Photography
HDR: High Dynamic Range
HFR high framerate
SDR: Standard Dynamic Range
LED: Light Emitting Diode
ML: Machine Learnning
SMPTE: Society of Motion Picture Technicians and Engineers
SPD : spectral power distribution
USD: Universal Scene Description
VES: Visual Effects Sociecty
VFX: Visual Effects
VR: Virtual Reality
XR: eXtended Reality

For a dedicated Virtual Production Glossary visit https://www.vpglossary.com

B. Virtual Production Use Cases

Virtual Production techniques can be used for a number of situations. It would be pretty rare that a project would be shot entirely in a LED volume, but for some sequences it can be highly beneficial from both a budget and carbon emissions standpoint.
We defined a list of common use cases:

Type of sequence	What VP replaces
Car process trailer	Physical trailer
Distant location	Team traveling
Fantasy environment	Green screen
Set extension	Green screen
Weather condition	Green screen

Car process trailer

Description

A very typical use of VP techniques is to shoot car scenes. The virtual environment is quite simple and can come from real location shooting (see our content preparation section) or 3D CG scene to provide more freedom on camera movements (or combinations).
The setup requirement is relatively small and does not necessarily require high resolution LEDs. In most cases, out of focus 2D content is enough and there is already plenty of stock shots available and even specialized vendors such as Driving Plates.

What VP replaces

Real process trailers require authorizations to shoot on real location or must ride on closed circuits. A lot of time is lost because of issues with shot continuity and weather conditions can seriously impact the schedule.

It is also possible to use green screen but depending on the camera angle, the light reflections and green spill management can be challenging.

Production benefits

- More shots per day
- Finer control of lighting and weather conditions
- More natural interaction of actors with the environment
- Security for the crew
- A much wider variety of possible camera angles, including from behind the driver

Environmental benefits

- No gas used for vehicles
- In the case of stock footage, CG scene or re-used plates, no impact from the background plate shooting, though the CG content creation process can be carbon intensive if it is very complex, comparable to a VFX shots.

Distant Location

Description

A shot in the desert, on the beach, at a specific location. Or it can be distant in time, like Paris in the 17th century. Virtual production can be really efficient at "bringing the location to the team": "*On Ripple Effect, we were able to execute and capture footage of our truck that spanned four locations and four different times of day all in one shoot day. "*

Image courtesy Entertainment Technology Center at the University of Southern California

What VP replaces

Moving the crew from location to location, with associated travel and accommodation emissions, and moving equipment and props if not available locally.

Production benefits

- More shots per day
- Finer control of lighting and weather conditions
- Less construction
- More natural interaction of actors with the environment than green screen
- Security for the crew in case of dangerous locations

Environmental benefits

- No travel to the location
- Less impact from construction

- Production of background plates should be easier to delegate to a local team than principal photography

Points of attention

- If the target location is considered for its landscapes, there is a good chance for wide shots and a large LED volume will be necessary

Fantasy environment

Description

A sequence in space, another planet, z fantasy world. Depending on the ambition of the sequence, the virtual set can be small or large.

What VP replaces

Mostly green screen shooting.

Production benefits

- Finer control of lighting than in post
- Less constructions
- Easier to integrate real props instead of green screen elements
- More natural interaction of actors with the environment
- Better alignment of artistic vision between CG and physical photography

Environmental benefits

- Probably less retakes in post-production

Points of attention

- If a large number of shooting days are in the Volume the power consumption impact may overcome the benefits of reduced post-production

Window set extension

Description

The shot or sequence has a window. Except in a case of a static camera, 3D ICVFX are required. The LED wall needs to be a little larger than the window.

What VP replaces

The use of a green screen.

Production benefits

- Reduced post-production time compared to green screen
- Finer control of lighting than in post
- Less setup time to manage different lighting conditions (time of day)
- More natural interaction of actors with the environment

Environmental benefits

- Reduced time in post-production

Points of attention

- Enough preparation so a simple shot does not turn into a complex VFX shot

Weather conditions / Time of the day

Description

A sequence that must be shot at a certain time of the day or with certain weather conditions: storm, rain, etc.

What VP replaces

Waiting for the right time or green screen shooting

Production benefits

- More shots per day
- Fine control of lighting and weather conditions
- More natural interaction of actors with the environment

Environmental benefits

- Reduced travels
- Less production time

Technical limitations

Color issues

LED lights are far from having the same color quality as the sun, because their Spectral Power Distribution (SPD) presents peaks. This means that some colors will be much more difficult to represent because there is not much power at the right wavelength, and unfortunately skin tones are often concerned. This can be more or less compensated by make-up and color grading, but sometimes it can turn into real issues.

Color precision can also be an issue as cheaper LED controllers do not have enough steps to represent all the nuances in colors.

In general the Digital Imaging Technician (DIT) and Director of Photography (DoP) would tweak the signal to make the result acceptable, but in the case of a high-profile production where color accuracy is expected or when some precise colors are expected, in the case of brand logos for example, it can be an issue.

The interaction with the camera color spectral response can also create problems so tests are necessary to make sure lighting, LED, objects and people present in the volume and the camera do behave together well.

Camera issues

As much as Virtual Production gives a lot more freedom and better interaction between actors, crew and virtual scene, to provide more natural looking interactions, such as light reflection, correct eyes direction, camera movements, it also has some limitations that can impede the creative process:

Limitations on framing
Depending on the size and geometry of the LED volume, some camera angles are impossible or necessitate extra extensions in post VFX. Also, as the displays are by default supposed to be aligned to one camera, shooting 2 camera point of views at the same time can be a real challenge.

Limitations on camera movements and speed
Despite the very high refresh rate of LED panels (a Roe Black Pearl v2 can do 7680Hz) the limitation on framerate comes from the connectivity (Display Port or HDMI) or the capacity of the content source (video server or real-time engine) to deliver high refreshing rates (HFR) to the displays, while it may be necessary for some camera effects.

On the Ripple effect, the result of camera test did show that there are only a few camera shutter angles that can be used for different capture framerates, which is also a limitation of artistic choices for the motion look;

“Testing Motion in front of LED wall is critical. Applying materials and movement in front of the LED Walls adds complexity and can magnify screen issues.” p95, Ripple Effect White Paper

Overview

With those examples of shots and sequence it is easier to understand where the Virtual Set inscribes itself in the production workflow. From the experience of technicians who have been working on projects using Virtual Production techniques, they provide the most benefit when they are well planned. Brian Gaffney at Unity sums it up in one sentence: "The “fix it in post” saying needs to be rethought".

Is Virtual Production for every production?

After 2 years in the fields it can be said that Virtual Production does not work with all producers and directors. As it takes a lot of important artistic and budget decision to be made before the shooting, some people who are more used to make their decisions on the fly and during the shoot and post production steps, can be dismayed by this new process.

As Jeremie Tondowski from Neoset puts it, “it works better for an industrial vision of content production”. TV series with a strong production team that plan everything to optimize resource usage have a powerful tool to integrate in their routine.

What is very interesting is that the decision process can be much accelerated by the use of real-time tools, in the continuity of processes. Once the art department, the DoP and the director have started to play with Previs and to interact with the VFX team in a digital environment that builds up as their vision develops, it becomes much easier to communicate complex intentions and get more deeply involved in the technical process.

Romain Cheminade, CEO at Dark Matters, describe this evolution as a “great opportunity to get more efficient in the creative process as people work better together and use the same language”. Creative teams that have been using Previs in the past know how this benefits to the production efficiency, but until now this has been used mainly on VFX intensive projects.

The speed of the process and the interactivity allows to get creative decision made earlier in the process and reduces the iteration numbers to get to the desired result.

C. Different configurations of Virtual Studios

Diversity in size and shape

It is important to notice that there is a vast diversity in the installations present today on the market. Permanent virtual stages range from small, curved walls of a few meters or “cubes” to huge volume such as the one at Pixomondo in Toronto or V Stage in the UK with more than 2,600 LED panels integrated with a motorized ceiling offering. Some are equipped with floors and ceiling, and some volumes are built out of mobile components on regular sound stages for more flexibility. As a general trade, we will see more and more of these purpose-built setups as manufacturers make it easier to move components around. It makes it easier to match studio space and equipment, for example to split teams and equipment between several stages.

Some companies like Les Tontons Truqueurs in the South of France use VP techniques without using LED walls, and they get the benefit of real-time compositing over green screen shots, that may be refined, or not, in post.

Diversity in picture quality

As seen in the physical components section, LED tiles have different specifications, not only in pitch, which translates into picture resolution during capture, but also in precision and color reproduction capabilities. The difference in price between lower precision event equipment, TV and cinema grade LEDs is significant. Experience in production shows that lower quality tiles can be used in less critical positions, such as ceiling and secondary mobile “reflections” units.

Some productions request specifically high specifications for the equipment used, as they do for cameras. The main reason is that post processes such as final color grading might in some situation made be difficult by lack of precision or color richness in the captured image, artifacts sometimes difficult to spot on set. It is an important consideration for the lifecycle management of LED tiles that can be moved from high quality requirement setups to secondary grade.

During the Covid crisis live event companies stopped their activities and installed their LED walls in studios as there was a need for production to shoot while travels were restricted and with a good control of people’s movement, which the studio environment makes much simpler. It was a good time to experiment and find out about the opportunities and limitations with equipment not designed for film and TV production. It appears that LED walls with not the highest color precision or pixel resolution can fit a lot of production purposes, but they can also create some real issues in the post-process, if issues have not been detected on set. This is particularly critical for film productions where pictures seen on a cinema projector reveal moire and banding artifacts that were not spotted on smaller screen during the shooting. As for anything else, testing and preparation are key to avoid these kinds of situations.

D. Virtual Studios hardware components

A typical virtual set is made of LED tiles attached to metal structures. These structures can be mobile or not, depending on the size and purpose of the virtual set.

The design, deployment and operation of virtual sets is complex: technical visualization, preview, virtual environment, rendering, synchronization, tracking, aggregation of filming information, coordination with the set team, props, make-up... And requires an exceptionally large bill of equipment.

Creating a virtual stage implies assembling the following elements:

- LED wall (depending on its surface, we might need to incorporate hundreds of led tiles)
- Digital asset in full 3D (station unreal engine) or photogrammetry (production and management)
- Tracking systems
- Cinema light (HMI and LED) to illuminate the stage and subjects
- Machinery (i.e., crane, robots, steady)
- Rendering servers
- Camera
- A quantity of wires
- Cloud architecture for storage/back-up
- Electricity distribution
- Sound system
- Post-production and colour grading process on set (working stations)
- Cooling system for the server room.

Most of this equipment is manufactured in Asia: LED tiles all come from Shenzhen in South China, and incorporate **many critical materials**[2].

LED Walls

An LED wall is made of tiles that are borderless screens so there is no visible separation between them when they are stacked and aligned. All tiles are assembled jointly so the seamless arrangement can be perceived as one single surface. It is a matrix of pixels, each made of several LED, Light Emitting Diodes, for the different color components.

LED tiles have a spatial resolution, which is defined by the pitch, the distance between pixels.
The number of pixels per square meters defines the precision of the image, which is important for high resolution production cameras.

The LED technology is relatively mature as it has been used for a long time in digital signage, stages and advertisement both indoors and outdoors, potentially running 24/7. Cabinets are sturdy and can run in a variety of conditions, and well-maintained modules can last 8-10 years. LED walls have also

2 Critical raw materials (europa.eu)

been used on live events and TV show for a number of years to create visual effects and dynamic displays.

The usage with high quality cinema cameras is recent though, and quality expectations are much higher in this context. Some purpose-designed products such as the Roe Black Panel provide high precision processing and large colour rendition capabilities.

LED walls may be arranged in Volumes that are designed to cover a variety of camera angles. Depending on the building structure and production requirements, those volumes can be arranged in different geometric configurations, with concave or straight LED walls, full or partial LED ceiling and floor. There are also mobile planes on wheels that can be used to help for lighting and reflections.

For example, for the Pixomondo studio in Toronto, Canada, the complete LED installation comprises approximately 2500 Black Pearl BP2 V2 LED panels, and the LED ceiling consists of 760 Carbon Series CB5 LED panels.

Video controllers and distributors

Each LED tile is connected to a video controller. This processing box is in charge of splitting the original video signal sent by the video source. This is also where some color processing can be applied to compensate the color discrepancy between the panel and adjust the signal to cameras if necessary. The color correction process, called calibration, is performed regularly by measuring the tiles with a color probe, so the colour patches appear all the same. Depending on the size of the setup, multiple controllers may be needed. Current state of the art controller such as Brompton SX40 can handle 4K at 60Hz (4096x2160@60)

Combined with distributors the signal can be cut and dispatched across multiple panels and geometries to address different types of production configurations.

Video sources

The video source can either be a video server, playing video files (2D ICVFX), or a graphic workstation with a real-time render engine such as Unreal Engine or Unity for calculating the projection of a 3D scene (3D ICVFX). Some software editors use those real-time render engines and have developed more dedicated tools for the particular use of Virtual Production, that must connect the information coming from a multitude of devices, such as light controllers, motion capture systems, camera tracking systems, etc.

A good example is Disguise, that also designed a set of hardware components to provide a fully integrated solution.

To cover a large area with a high resolution it is necessary to use multiple video sources:

- In the case of 2D ICVFX it requires to synchronize the video servers to send on the multiple video processors.

- In 3D ICVFX the task of rendering 3D scenes on multiple machines in real-time and recombining them at a very low latency (usually below 3 frames) so it is acceptable for fast camera movements is a huge technical challenge.

Video Infrastructure

To carry the signal and combine different sources there may be a video mixer, that can also use for multiple operations such as real-time compositing for preview, and routing the signal to multiple outputs.

IT Infrastructure

The IT infrastructure of a Virtual Studio is similar to a post-production house, meaning it usually combines:

- workstations
- storage servers
- rendering servers
- archiving tape robot
- communication systems : cloud, videoconferencing

Lights

The LED Walls do emit light but extra fixtures can be added when the scene requires strong sources. For that purpose, the ceiling is often modular and allows to get suspended lights through.

Camera equipment

Production equipment such as light, cameras, rigs, tripods, jib arms and cranes, is generally rented. Sometimes studios partner with vendors for some specific tools such as robotic arms that have been customized or built on purpose for more precision or extended capabilities in the VP environment.

Tracking technologies

The main component to be tracked is the camera as the virtual camera that generates the point of view displayed on the LEDs must be very precisely matched with the smallest latency possible.

The head can be mounted on a stand or a crane, a dolly or other machinery. The information of position, angles and speed are transmitted as data to the display engine. A calibration to match exactly the physical camera focus and position is necessary before shooting.

For handheld camera shots, wireless tracking device can be mounted on the camera. Several technologies are available on the market, from basic VR movement trackers to full room motion capture systems.

In some cases, it can also be interesting to capture the movement of people and objects relative to the camera. All motion information, from actors and camera, is recorded to be used in the computer graphics environment to generate a character animation to be recomposited in the camera viewfinder. Facial capture can also be recorded at the same time so all of the actor's performance is in sync. This combination of technologies, called Performance Capture, has been in use on for CG intensive projects for a number of years, it can be integrated within a Virtual Production workflow.

Grid and structure

The LED walls need to be securely attached to a structure, considering their density (36,5 kg/m2 without cables), a large volume could total more than 20 tons without structure, the structure itself being between 30 and 40 tons. This is not a load that every studio floor can handle.

E. Virtual Production Workflow steps

Virtual Production techniques rearrange the efforts put in different steps of the production. They may be involved during pre-production with Previs and build a continuity of the artistic intent all along the production workflow or be used only on some punctual steps.

Virtual Art Department

The Virtual Art Department starts to build the content to be displayed in the screens during pre-production.

Previs

The production can start from rough models and animations for the ideation purpose during the Previs stage: the creative team can try different arrangements of scenes, camera angles, etc. Previs can also be used for other departments to set their own equipment and see the constraints before they happen (TechVis, StuntVis, SecurityVis)

In that regard Previs approaches the concept of digital twin that is used on some organisations such as complex buildings or airports. Previs is not specific to Virtual Production and has been used for a long time for complex shots, but Virtual Production gives it more sense for the creative team as it gives continuity in the project vision:

« It includes stuntvis, whereby action designers can safely and confidently plan their scenes in a real-time game engine that has accurate physics and a 1-to-1 relationship to the physical world.
It includes techvis, whereby a crew visualizes the physical filming environment ahead of time, accurately determining which lenses they should use and which camera angles will best capture the shot. It's also used for remote collaboration, in which the filmmaking team enters a virtual scene in VR or on a monitor and can then scout locations and art-direct all together interactively, regardless of where they are. » Miles Perkins, Epic Games[3]

Once all decisions are made, they can be recorded as videos and sent to the team. Camera angles and positions set in the virtual environment can be sent as data to control a robotic arm.
Once all information from Previs and shooting are recorded, they are integrated altogether within the digital system for verification and as a starting point for post-production.[4]

Content to be used as background can come from different sources. In this section, all the techniques described have been used in traditional visual effects and computer graphics animation.

Plates creation

As in traditional green screen composition, some live action footage can be captured to be put in the background. The capture can be made from rigs of multiple cameras or 360° VR cameras, potentially mounted on cars or drones.

3 Source https://postperspective.com/a-new-era-of-entertainment/
4 Source:https://www.foundry.com/insights/vr-ar-mr/virtual-production-workflows

Those plates need to be shot with the right lens, same camera distance and settings compatible with the setup that will be used for the virtual set shooting, otherwise some of the content would have wrong perspectives and sizes. These effects can be avoided by some picture editing during content preparation.

Depending on the type of rig used for capture, images may need to be stitched together to create a large, high-resolution image, and have their geometry and colors adjusted to adapt to the displaying conditions. Elements can also be added or removed with compositing and painting software tools.

3D scene capture

There are different techniques to digitize 3D scenes so they can be manipulated into a Computer Graphics environment.

3D Scanners can be used to scan objects, they emit light that is captured by a camera and the signal is processed to generate a cloud of points, then connected and simplified to generate surfaces in the computer graphics environment. They can be handheld or attached to some rigs depending on the size and accessibility of the objects to scan.

*Image court*esy of Artec 3D - www.artec3d.com

Digital Photogrammetry is a technique to extract 3D information from multiple pictures. It is an old technique that can be deployed in a variety of setup, from planes or drones destined for large areas to studio size cages with multiple cameras capable of capturing moving objects or humans.

Image courtesy of UMBC Imaging Research Center

LIDAR is also used for 3D capture, depending on the application it can also complement or replace photogrammetry for more precision. LiDAR is not affected by weather conditions, such as cloud cover and changing lighting conditions which can greatly disrupt aerial data collection for photogrammetry.

For 3D ICVFX using 3D scans of a real scenery can be tricky as the level of details needs to be adapted to the performance of the system for real-time playback. Also, some landmarks can be subject to copyright (see in the Asset Management section).

3D Modeling

3D Modeling for real-time rendering takes special approach as the performance is greatly affected by the precision, the number of polygons and effects, in the scene. As for traditional visual effects some assets are designed to look good from the camera point of view, like stage flats. On the opposite, some will be fully detailed so the object can move freely on all axis and/or the camera can turn around it.
There is no specific Digital Content Creation tool (DCC) used for Virtual Production, though more and more operations happen directly in the render engine interface. Software editors such as Autodesk (Maya) or SideFX (Houdini) develop plugins for Unreal and Unity to allow for better interaction between their toolset and the real-time environment.

In the case of Previs, rough models and animation are used to help the staging of elements in the scene and placement of camera. This interactive 3D storyboard helps the planning and the budget of the production and makes it easier for the whole crew to communicate on the expected results.

The process of building the 3D scene is relying more and more on picking assets from a library. As studios standardize their process and the industry progress on interoperability solutions (see the Asset Management section) it will be easier to retrieve and reuse geometries and textures.

Rendering

To allow for better playback performance during the camera capture some tricks can be used to avoid the full calculation of all parameters in the CG scene. Partial rendering (**baking**) is a technique used in video games to pre-calculate computing heavy effects such as complex light reflections and textures behaviors. By optimizing the scene, the final render, processed by the real-time engine, can be much faster. This is also a way to avoid some limitations of real-time rendering technologies.

Compositing

To produce the content displayed in the Volume sometimes plates are combined together, edited to add and remove some components, distorted to compensate for lenses, color corrected… the whole result can be compiled as one layer or left as several layers managed independently by the playback system.

LED Volume setup

Physical geometry setup

Before the shooting, the set is prepared and configured, in the case of a mobile wall or volume, technicians install and configure it. A part of the configuration is the color calibration, to make sure all tiles display the same colors. This process is partly automatized with cameras and software tools that communicate with the video controller.

Content loading and verification

The digital scenes are loaded and checked to detect errors and artifacts. Tracking and motorized devices are connected and checked.

Camera calibration and tests

On projects where the background is in focus and matching expectations for movement and color are high, the camera and lenses are analyzed to create profiles of color and geometry distortion. These profiles are then loaded in the render engine and fine tuned with the DIT and DoP to obtain the best integration between the digital and physical photography.

Shooting

The shooting is the most critical part. Operating the playback systems and synchronizing with the production team takes a couple of technicians. Communication with the camera department is key as issues and artifacts must be detected as soon as possible. A Digital Image Technician checks the matching of colors between the camera and the background and works with the LED wall technicians in case of issues.

Some studios have developed their own interface to pilot their custom setup and provide better interactivity to technicians. There is also a lot of apps and utilities that are developed to facilitate the interaction with equipment such as controlled lights, robotic arms and camera heads.

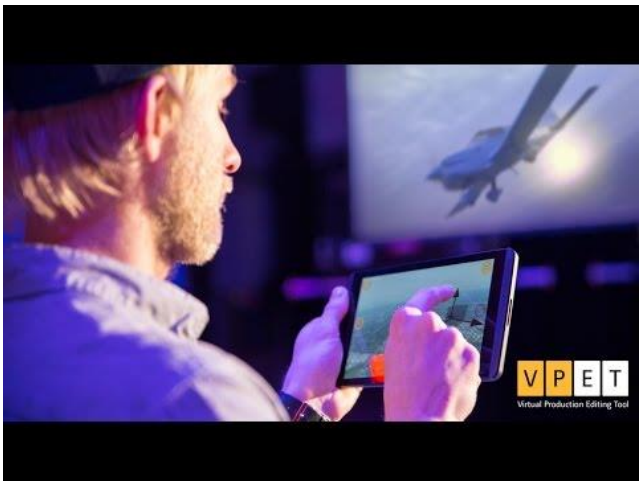


Image courtesy of Animationsinstitut, Filmakademie Baden-Württemberg

Post-production

VFX

As the digital world is pre-generated and based on real scale, post-production can easily add and remove elements from the scene. The most difficult part is to fix LED walls or camera issues that could not be managed during shooting (content lagging, moire effects, color artifacts...)

Volumetric effects such as rain and smoke and set extensions beyond the volume can also be added.

Editing

Virtual Production is an opportunity to provide a visual continuity with the script though it would be the case mostly on VFX intensive projects. The opportunity to interact between Previs, Virtual Production and the editorial department should be taken to provide all crew members with a better view of the project as a whole.

Color Grading

The finishing part still happens after the final conform during the color grading session, where the colorist will refine the look defined with the DoP. This task can benefit from information coming from the stage, such as tracking information, to separate elements of the scene.

Mastering

The content is then packaged at the final file format, combined with sound versions and subtitles, checked and delivered. There is nothing specific for Virtual Production at this step.

F. Health impacts of Virtual Stages

Blue light emission and high brightness

As we saw in the Color Issues section, LED have a Spectral Power Distribution with a strong spike in the blues, which harms retina. It is already a problem with home lighting and direct view displays such as phones and computer monitors. Some medical publications expose the phototoxicity of LED lighting. As a preventive measure, protective glasses should be worn by all crew during operations considering the high luminance of this particular use.[5]

Motion sickness and mental health

On a more physiological aspect, immersive studios with powerful lighting do have an impact on the perception, especially considering the movement of images following the camera fulcrum being non consistent with the body position in the physical space. Studies may be conducted on the impact of working in such environment for the crew to evaluate the health risks. As in VR where motion sickness is known, there may be some good practices to develop and tests that may be inserted in the signal chain as equivalent to the Photosensitive Epilepsy Analysis Tool (PEAT)[6]

Other potential hazards

Gas emissions may also be an issue as electronics and LED substrate can reach high temperatures. Studies may be conducted to have a better understanding of this impact.

5 Source:https://pubmed.ncbi.nlm.nih.gov/32317708/

6 Sources: https://www.livescience.com/what-causes-motion-sickness-in-vr and https://trace.umd.edu/peat/

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The newer version, StEM2, was shot digitally and provides elements to evaluate HDR and HFR technologies. Some sequences of the StEM2 were shot in a virtual set - https://theasc.com/asc/stem2

Find Studios

https://vpdb.sequinar.com

https://ledstages.info/

Carbon Calculators

Those carbon calculators have been designed to help the media industry have a better understanding of its carbon emissions

- Albert
- Carbon Clap
- Eureca
- PEAR

GHG Assessment Data

Data used for calculation of carbon impact:

Study from Filmakademie Baden-Württemberg
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Final Pixel Academy
https://finalpixelacademy.com/

Online training
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Here is a non exhaustive list of articles used for this study

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About this study

Workflowers

Workflowers is a brand created in 2006 to help the transition of the cinema industry from film to digital. Rebooted in 2020, Workflowers now provide services for the media industry to manage its transition towards more sustainable models. This includes training and consulting and the development of software tools to modelize, implement and track sobriety and GHG emissions reduction strategies.

Workflowers works for media groups (Canal+,TF1), studios (Ooolala, Supamonks, Fix Studio), associations and industry projects (Ecoprod, Green Screen).

Workflowers is a member of the DPP, Cap Digital, French Tech in the Alps, France Digitale, Minalogic, Tech for Care, Digital League.

More information on www.workflowers.net and www.carbonpilot.io

Main writer

Cedric Lejeune, is a media engineer who has been a pioneer in digital cinema technologies and helped facilities all around the world transition from film to digital. As an expert of color management, production workflows and storage technologies for media, he has experienced many of the technology breakthroughs that led to the possibility of Virtual Production, including motion capture, previs, realtime graphics, LED walls and cloud technologies. Cedric is a member of SMPTE, HPA, VES and the co-head of post-production department at CST.

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