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The evolutionary disruption: A paradigm shift in film and animation industry driven by real-time rendering and virtual production

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Abstract

This paper explores the paradigm shift in the film and animation industry driven by the advent of real-time rendering technology. Through an approach combining qualitative interviews with industry practitioners and quantitative analysis of survey data, the study delves into the multifaceted impact of this technology. The research highlights the technology's potential to enhance creativity, speed, and efficiency in production, while also emphasizing the challenges it poses, including technical complexities and the need for specialized knowledge. A notable theme of democratization emerges, with participants indicating that real-time rendering can help make high-quality production tools more accessible and enable a broader range of creators to participate in the industry. This study also reflects on the complexities of technological democratization, emphasizing that access to real-time tools remains uneven and shaped by broader structural factors.

Keywords

real-time rendering, virtual production, creative experimentation, non-linear production, democratization of filmmaking

Introduction

In the film and animation industry, technological innovations have consistently redefined the boundaries of creativity, stretching the realms of possibility and reshaping the manner in which stories are conceived, crafted, and conveyed. One of the most recent technological developments is the adoption of real-time rendering technology to enable 'virtual production' (Tovell and Williams, 2018). From small studios to major film conglomerates, the ripple effects of this advancement are

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significant, influencing various facets of the industry from the conceptualization phase right up to the final cut (Silva Jasaui et al., 2024). Recent scholarship has sought to further define and diversify the conceptual boundaries of virtual production. While the term remains fluid and often context-dependent, emerging works attempt to frame virtual production not simply as a technical pipeline, but as a creative, cultural, and collaborative shift within screen industries. For instance, Barnett, Bevan, Mackness and Wallin's Beyond Virtual Production offers a practice-led inquiry into how virtual production reconfigures roles, authorship, and creative control, especially in hybrid and experimental formats (Barnett et al., 2025). Swords and Willment contribute to this discourse by articulating virtual production as a constellation of interdisciplinary practices, also highlighting the tensions between democratization and production labor in both established and emergent studios (Swords and Willment, 2024). As the frontier of filmmaking evolves, so does the discourse on its implications, both artistically and operationally.

Real-time rendering is the process of generating continuous high frame-rate images near-instantaneously in response to user input (Pharr et al., 2023). The genesis of real-time rendering in films can be traced back to its application in the gaming industry, where the need for immediate, dynamic, and responsive visual representation was paramount (Pires et al., 2022). While conventional filmmaking has primarily relied on a linear structure, following a sequential path from planning to filming and post-production, real-time rendering technology enables a less linear approach (Kadner, 2019: 6). This pivot not only reshapes the structure of production but reorients the creative mindset from thinking in terms of isolated shots to more holistic scenes or levels (Pires et al., 2022). The shift is not just procedural but conceptual, marking a departure from traditional methodologies.

However, the narrative surrounding real-time rendering is not without its complexities. It conjures up a gamut of responses from industry professionals, from those who hail it as a revolution, extolling its transformative impact, especially on smaller studios, to others who perceive it more as an evolutionary step, lauding its efficiency but underscoring the difference in quality compared to offline rendering (Everhardt, 2018; Studio, 2024) .Furthermore, real-time rendering is woven into the discourse on the democratization of filmmaking (Cook, 2020; Rogers, 2020). The accessibility and affordability of cutting-edge tools, such as Unreal Engine and Unity, is potentially closing the gap between what small independent studios and larger players can produce. (FAILES, 2021)

Yet, with the rapid development of this technology, several questions loom large. How does real-time rendering technology affect the animation creation process? What are the perceptual, operational, and philosophical shifts it engenders among industry professionals? Moreover, as the lines blur between traditional filmmaking and game-based concepts, what are the broader implications for storytelling, aesthetics, and industry dynamics? Does increased access to these tools truly equate to democratization, or do deeper structural barriers continue to shape who can meaningfully participate in this new production paradigm?

This research delves into these questions, anchored by a series of interviews with professionals spanning diverse niches within the industry – from directors and VFX artists to academics and independent artists. Through their insights, experiences, and perspectives, this study looks to weave a cohesive narrative on the impact of real-time rendering and virtual production, aiming to paint a holistic picture of the current landscape and forecast the contours of the future.

A paradigmatic transformation in animation creation

The animation industry, historically rooted in hand-drawn sketches and painstaking frame-by-frame processes, has witnessed a series of technological evolutions including digital ink and paint,

computer-generated imagery, motion capture technology and many others. The relatively recent introduction of real-time rendering and virtual production technologies appears to be driving a significant shift in the animation creation process. This shift, while enabled by technical innovations, extends to the philosophical, methodological, and narrative dimensions of animation creation.

From linearity to non-linearity

Traditionally, animation followed a linear process. It began with storyboarding, followed by designing, animating, and finally rendering (Russo, 2021). Each step was sequential, with the next phase beginning only after the previous one was completed. This linearity was a result of both technological constraints and the established methodologies of the time. The introduction of real-time rendering technology disrupted this linear workflow. Creators could now see the results of their work instantly, without waiting for lengthy render times. This immediacy allowed for immediate feedback, enabling animators to make on-the-spot adjustments, fostering a more iterative and dynamic creation process.

Jon Favreau's 2019 adaptation of 'The Lion King' is a typical example in the realm of animation and virtual production. While it was marketed as a 'live-action' film, it was, in essence, a fully animated movie that utilized innovative technology and techniques (Failes, 2019). The film's production process, as described to Failes, uses a non-linear production approach, where virtual environments and characters were built in a game engine, allowing the filmmakers to explore and adjust scenes dynamically in real-time, rather than following a fixed, linear pipeline. This shift allows for more flexibility, adaptability, and interactivity. It offers creators creative freedom but also brings challenges we will discuss in subsequent sections (2.4 New storytelling possibilities).

Enhanced collaboration

The advent of real-time rendering techniques has shifted the workflow in the animation and film industry, not just in terms of visual capabilities but also in the dynamics of collaboration. The traditional linear workflow, where each department worked in sequence, often in isolation, has been transformed into a more integrated, simultaneous process.

The main change is the arrival of simultaneous input and feedback. Historically, departments like modeling, texturing, lighting, and VFX often worked in silos, with minimal interaction until their specific phase of the project (De Carvalho Cruz and Xavier Natario Teixeira, 2021; Dunlop, 2014). Real-time rendering breaks down these barriers. Now, a lighting expert can work alongside a texture artist, adjusting in real-time to achieve the desired aesthetic, fostering a more holistic creation process (Bousquet, 2022). Another change is that real-time decision-making can now take place. In traditional workflows, decisions about VFX or certain animation elements might be postponed until post-production. With real-time rendering, some of these decisions can be made on the spot during initial stages, helping to ensure that all departments are working towards a unified vision from the outset. Because of this, the nature and style of communications between departments is likely to change.

Democratization of filmmaking

Advanced real-time rendering is becoming more accessible, even on consumer-grade hardware. This means that indie filmmakers and small studios can achieve high-quality visuals that were once reserved for big-budget productions.

A good case for the democratization of filmmaking is the independent film, *Construct,* by Kevin Margo (Chico, 2014). Typically, indie films, due to budget constraints, rely on practical effects or limit the scope of visual effects. However, *Construct* aspired for a visually intensive narrative, which would have traditionally required a significant budget and extensive post-production. Margo used NVIDIA GPUs and the Chaos Group's Project Lavina for real-time ray tracing, streamlining the animation creation process, and drastically reducing the production timeline compared to traditional methods (Clee, 2018). This project demonstrated that you do not need a Hollywood budget to harness the power of real-time rendering. He attributes the film's success to the cost efficiency, creative flexibility and streamlined production that real-time rendering game engine brings.

Vashi Nedomansky, an indie filmmaker shared his experience on Vashi Visuals, illustrating the transformative power of Unreal Engine in creating immersive film environments on a budget (Nedomansky, 2023). By utilizing a virtual stage and Unreal Engine, his team was able to capture extensive footage with a variety of environments in a single day, a feat that would traditionally take much longer and come at a higher cost. His video only used a Dell workstation (DELL Precision 7865 Tower) with an NVIDIA RTX A6000 GPU. The process involved real-time adjustments to the scenes, allowing for instant feedback and eliminating the need for extensive post-production work.

Both case studies underscore the broader trend of democratizing filmmaking through technology. As real-time rendering tools become more user-friendly and accessible, they open-up new avenues for creative storytelling, allowing indie filmmakers to produce work that competes with big studios in terms of visual quality and storytelling depth. This shift is not just about the technology itself but about giving creators more control over their creative process and enabling them to produce better quality work than would otherwise be possible without access to traditional film production logistics and budgets.

New storytelling possibilities

With the ability to manipulate environments and characters in real-time, storytellers are less bound by the constraints of the physical world. This opens up new narrative possibilities and genres. Traditional animation often involves planning camera movements in advance, with almost no flexibility for free movement during the production process. In contrast, 'The Lion King' (2019) allowed for much more flexible and responsive camera movements. Cinematographers could 'operate' virtual cameras within the VR environment, capturing scenes with the same spontaneity and creativity as a live-action shoot (Kadner, 2021: 65). Game engines are designed to create immersive, interactive environments where the narrative unfolds within a spatially coherent, dynamic setting. This environment allows for real-time interaction, enabling cinematographers to explore and manipulate the virtual space in ways previously unattainable with traditional tools. As a result, in a game engine, creators are likely to think in terms of scenes or levels rather than shots (Antunes, 2019).

Another example of effective virtual production use comes from digital agency Imagination. They produced a short film that utilized Unreal Engine for creating immersive experiences (Imagination, 2021). Imagination embarked on a journey to leverage virtual production technology, culminating in the creation of a narrative set in a near-future dystopian world. This project highlighted several advantages of virtual production, including the ability to create powerful storytelling moments by minimizing the gap between concept and execution, adapt lighting and environments in real-time, and incorporate reflective surfaces without the need for extensive post-production. The work demonstrated how virtual production can be used to tell stories that blend physical and digital elements seamlessly without the need for a traditional non-real-time pipeline.

However, we should always notice that real-time rendering does not inherently improve narrative quality but rather expands the diversity and immediacy of storytelling modes. Practitioners can prototype, iterate, and visualize stories in real time, allowing for new forms of creative exploration – particularly in non-linear, interactive, or immersive contexts. This technological shift fosters not necessarily 'superior' storytelling, but alternative narrative structures that may better suit the demands of emerging media platforms and audience expectations.

Methodology

In order to explore the multifaceted implications of real-time rendering and virtual production in film and animation, our research adopted a methodology which combined qualitative and quantitative data collection and analysis methods.

Qualitative data collection and analysis

For this research, a qualitative analysis was conducted using Strauss & Corbin's method (Corbin and Strauss, 2014), to ensure a thorough and systematic exploration of the data. The process commenced with recording the interviews, which were then translated from audio to text. Given the expansive scope of the subject, we aimed to recruit a diverse range of participants, ensuring representation from different sections of the industry. We used a purposive sampling technique to select directors and producers who have adopted or explored real-time rendering in their projects, VFX artists and technical directors at the forefront of experimenting with this technology, academics involved in studying film and animation technologies and educating students in the field, and independent artists using real-time rendering platforms such as Unreal Engine and Unity. The study includes 15 in-depth interviews, conducted either face-to-face or via Zoom. Among these participants, 12 were based in Australia, 2 in China, and 1 in Singapore.

A blend of semi-structured interviews and open-ended discussions was employed to gather data. This methodology ensured that while key topics were covered consistently across interviews, there was ample space for participants to share spontaneous insights and anecdotes. Although each interview was tailored to the specific expertise of the participant, the discussions consistently explored several thematic areas. These included personal and professional experiences with real-time rendering, perceived advantages and challenges of the technology, a comparative analysis of real-time versus offline rendering in terms of quality and efficiency, insights into the broader implications for storytelling, aesthetics, and industry dynamics, as well as speculations and forecasts on the future trajectory of real-time rendering in the industry.

The AI tool, ChatGPT (ChatGPT4.0 August 3, 2023 Version), was employed to streamline the coding process due to its proficiency in handling text and identifying patterns. Given the token limitations of ChatGPT at the time of writing, the content of the interviews was summarized manually to retain core meanings while trimming redundant or non-essential details. This concise representation ensured efficient processing while staying within the constraints of the AI tool. All personally identifiable information was removed during this summarization process. The coding process involved multiple stages: open coding to identify initial themes, axial coding to explore the relationships between the identified themes, and selective coding to refine and prioritize these themes. We conducted a manual review of the themes and codes generated by ChatGPT to validate accuracy and relevance. Further details of the coding process can be found in Appendix II.

Quantitative data collection and analysis

An online survey was designed to gather broader input from a larger number of participants and facilitate quantitative analysis.

Survey design. An online survey, consisting of 15 questions gauging attitudes towards, and perceptions of, real-time rendering technology was administered to directors and other practitioners (Appendix I). The questions were formulated based on the themes and patterns identified during the qualitative analysis to further probe and validate those findings.

Sample selection. The target respondents for the survey were professionals within the animation and filmmaking domain from the researchers' networks and professional public forums such as the Epic Unreal Engine official forum and Virtual Production with Unreal Engine discord server.

Data analysis. The questions were categorized into two groups based on the research objectives. The first group is Attitudes towards Adoption of Real-Time Rendering Technology, which pertains to how practitioners feel about integrating real-time rendering into their workflow and the impact it has had on their creative process. The other group is Real-Time Rendering Technology Trends, which pertains to the current and future state of real-time rendering technology, its accessibility, and its potential to influence or disrupt the industry. The full questionnaire is shown in Appendix I and the code of each question is shown in the table below.

Based on the categorization, correlation analysis within groups and comparative analysis between groups were performed.

Ethical considerations

Participants were informed about the purpose of the study, their rights, and the measures in place to protect their anonymity and confidentiality. Informed consent was obtained from all participants prior to data collection. (See details in UTS human research ethics ETH19-3452, attached in Appendix III)

Results and key findings

Perspectives of relevant practitioners on the adoption of real-time rendering technology

The advent of real-time rendering technology is clearly having an impact on the animation and film industry. The perspectives of practitioners, as gleaned from the interviews, can be categorized under three thematic codes: (1) Democratization; (2) Challenges; and (3) Optimism versus Caution.

Democratization of technology. Democratization, in the context of real-time rendering technology, refers to the process by which access to filmmaking tools, techniques, and platforms becomes more widespread, allowing a broader range of creators to participate in the industry. This shift is particularly evident in the perspectives of the interviewed practitioners.

The democratizing effect of real-time rendering technology is primarily driven by its accessibility and affordability. Bertrand Polivka, Lead Compositor at Cumulus VFX, highlights how game engines like Unreal have made high-quality film production achievable for smaller studios. These platforms, once exclusive to large studios with significant budgets, are now available to individual

creators and smaller entities. This shift has broken down barriers to entry, allowing more creators to bring their visions to life without the need for massive budgets or large teams.

> 'I think the democratization of the technology. [Using 2000 s technology]. you could scroll 8K so fast. But the machine was $1,000,000. ...but I think [now] you could run a nice Unreal 5 on like a $6000 PC'. Bertrand Polivka, Lead Compositor at Cumulus VFX.

Alex Weight, Creative Lead at UTS Animal Logic Academy, emphasizes the transformative nature of this technology for individual creators and small studios. He elaborates on the constraints previously faced by smaller studios, primarily in terms of human resource requirements and the financial demands associated with rendering, lighting, and software. Such constraints often meant that high-end production was unfeasible for smaller entities. However, with the integration of platforms like Unreal Engine, these limitations are substantially alleviated. A small team can now produce high-end work with relatively minimal financial investment, significantly broadening the scope for creative content production and making it more accessible for smaller studios to partake in innovative content creation.

> 'Look basically, the limitation of a small studio... is the amount of artists and cost. So if a small studio wants to create an animated TV show... the cost of rendering and lighting everything at the back end is quite expensive... With Unreal, you can have a small group of people create... high end work at a very small amount of money... It does open the doors for more creative content and it's more accessible now for smaller studios to create... creative content as well'. Alex Weight, Creative Lead at UTS Animal Logic Academy.

While democratization brings numerous advantages, it may also bring challenges. Alex stresses the potential for a decline in quality because of the increased ease of access to production tools. This accessibility enables a broader spectrum of individuals to generate content, potentially leading to a market oversaturation. Such a scenario raises concerns about the compromise of quality in favor of quantity. This challenge should not be viewed solely in a negative light, but it does suggest the industry may need to establish new mechanisms for quality control. Additionally, this evolution in the industry could catalyze a shift in audience engagement.

> '... When something becomes more accessible, everybody starts using it... but the quality drops. I imagine there'll be a lot of TV shows... homemade content that comes out pretty quickly, but only the good ones are going to start rising to the top'. Alex Weight, Creative Lead at UTS Animal Logic Academy

Resistance to change. While there's excitement about the potential of real-time rendering, there's also a palpable resistance to change. This resistance is evident in various ways, as highlighted by the interviewed practitioners.

One of the primary challenges is the shift of mindsets and workflows. One of the interviewees pointed out that creators think in terms of shots in traditional animations or films, while they need to shift to thinking in terms of scenes or levels in real-time projects.

> 'The main challenge in transferring from one to the other is that traditional filmmaking is in terms of shots, whereas real time projects, …are typically not broken down by shots, they're broken down by scenes or level maps so it can be very confronting and very challenging to adapt that mindset…if you try

> and use something like Unreal…in a very shot by shot process, you're not working necessarily in the way that the tool is designed…, you may not get the benefits out of the approach'. Michela Ledwidge, Creative & Technical Director, Founder at Mod Studio.

In traditional filmmaking, a 'shot' is the basic unit of production. It is a continuous view filmed by one camera without interruption. Filmmakers think in terms of shots to build scenes and sequences, focusing on camera angles, movements, and the composition of each individual shot. This approach is deeply ingrained in conventional filmmaking and animation processes. In contrast, a 'level' or 'scene' in real-time rendering, particularly in game engines like Unreal Engine, refers to a specific environment or setting where gameplay or narrative unfolds. It is not limited to a single camera angle or a moment in time but is an interactive space that players or viewers can explore. In real-time projects, content is often broken down by these environments or levels, rather than by individual shots. The shift from thinking in shots to levels requires a fundamental change in how creators approach storytelling and production. It demands a broader view of the narrative, considering how the entire environment interacts with and influences the story. This change necessitates a different workflow. In real-time rendering, the focus is on creating and refining entire scenes or levels, rather than meticulously planning individual shots. This approach allows for more dynamic and interactive storytelling, as it takes advantage of the exploratory nature of games and interactive media.

For interactive media like video games or VR experiences, thinking in terms of levels rather than shots is inherently more aligned with the medium's interactive nature. It allows for a more immersive and responsive experience for creators. It also offers more flexibility and immediacy in the creative process, enabling artists and developers to see and interact with their work in real-time. However, for practitioners deeply versed in traditional filmmaking, this shift can be daunting. It requires not only learning new tools and technologies but also adopting a completely different mindset in how to approach storytelling and production. Michela emphasizes that the change can be challenging and may initially lead to resistance, especially among those who have spent years mastering the art of shot-based storytelling. *'I think this goes for any industry or any process of change management when customers or partners who are very experienced in offline-based workflows look at real-time tools. They often say, well, we just needed a real-time tool that [works] exactly the way we're used to working. They're not necessarily open minded about changing their workflow to support new opportunities',* she said. The appropriateness of this shift also depends on the nature of the project. Michela emphasized that for certain types of narratives or productions, the traditional shot-based approach might still be more suitable.

Some interviewees expressed dissent regarding the term 'Virtual Production', illuminating a broader issue of resistance: the challenge of assimilating novel terminologies and theoretical constructs within the industry. The term 'Virtual Production' itself lacks a universally accepted, definitive characterization, leading to varied interpretations and understandings among practitioners. Certain interviewees perceive this term as somewhat of a misnomer, potentially functioning as a marketing construct that inadvertently reduces the intricate nuances of the production process to an overly simplified concept. This viewpoint suggests a skepticism towards the adoption of such new terminologies, positing that they may diminish the perceived complexity and sophistication inherent in production methodologies. This resistance is arguably rooted in the discomfort associated with integrating new linguistic constructs into professional vernacular. It also reflects apprehension regarding the potential for these terms to inadvertently trivialize the multifaceted nature of production processes. Such apprehension underscores a broader phenomenon in technological transitions: the tension between the need for new, descriptive language to encapsulate evolving practices and the imperative to preserve the integrity and depth of established professional methodologies.

> 'Do we have a clear definition for virtual production? Some refer to LED volumes... others to animation using real-time rendering engines like Unreal Engine or Unity. Is there a clear definition for the virtual production industry? If it's doing motion capture and seeing results right away, this is all I interpret it but it's very loose. Sometimes I think the terminology is a marketing thing'. Raphael Gadot, CG Lead at UTS ALA.

> 'This is a particular specialty area... the uneasy relationship between old and new language. The old-fashioned language from traditional film hasn't caught up with the new language of virtual production. There have been attempts to merge the languages, but they're not really working. Even the term "virtual production" is somewhat inaccurate... Language is one of the key problem areas'. Peter Herbert, Head of Screen Business and Producing at the Australian Film Television and Radio School (AFTRS).

> 'I would like to kill the term "virtual production." It's a marketing term... it can confuse people, like the term "Apple" – could be a fruit or a tech brand. When people use jargon, it often indicates either a lack of understanding or an effort to engage, even if they don't fully grasp the concept'. Krista Jordan, Discipline Lead, AFTRS.

The migration from conventional to real-time rendering pipelines is fraught with a plethora of technological impediments, posing practical difficulties that extend beyond theoretical understanding into the realm of operational execution. This transition, as expressed by several interviewees, is impeded by a series of technical challenges that encompass collaboration intricacies, project sharing complexities, and the imperative for enhanced source control mechanisms.

> 'Real-time rendering is like a Formula One car – precision designed and fast. To work in real-time, you must be efficient, but many VFX people are slow and inefficient. Sometimes, working in real-time can be slower... figuring out how to get it into Unreal can take days. It's about having a balanced approach'. Matt Hermans, Mixed Reality Creator at Electric Lens Co.

Some interviewees also mention that these technological hurdles present a formidable barrier in the adoption of new rendering techniques. Issues pertaining to the effective collaboration among diverse project teams, coupled with the intricacies of sharing and managing projects in real-time environments, underscore the necessity for robust and agile source control systems. Such systems are crucial in managing the intricate workflows and data intricacies inherent in real-time rendering processes.

> 'But the downside is there's a lot more preparation... You can't just turn up on set and film; you need to prepare virtual backgrounds, camera setups, and technical aspects... While there are artistic and process benefits, there may be even more preparation required'. Ross Anderson, CG Lead UTS ALA.

Some interviewees made that points that these technical challenges have the potential to dissuade practitioners from wholeheartedly embracing these novel methodologies. This reluctance is particularly pronounced among those who perceive their existing, traditional methods as sufficiently effective. The introduction of new technologies often demands a recalibration of established processes, which can be perceived as a complication, especially in scenarios where current methodologies are deemed to be performing well.

> '…I come from a traditional background where you go step-by-step. In real-time, you can do everything at the same time, and things change quickly... I'm learning and adapting, finding the right processes

because it's chaotic... It's a different structure that I'm not used to'. Raphael Gadot, CG Lead at UTS ALA.

Optimism versus caution. The adoption of real-time rendering technology in the animation and film industry has elicited a spectrum of reactions, ranging from optimism about its potential to caution regarding its implications. The interviewed practitioners' perspectives provide further understanding of this dichotomy.

Many industry experts perceive real-time rendering technology as a pivotal development. Michela Ledwidge regards the technology as fundamentally revolutionary. She posits that disregarding its potential equates to a creative oversight. However, her optimism is tempered by caution. She warns that if creators don't fully utilize the opportunities presented by real-time technology, the benefits may not be as clear. This caution reflects her belief that simply adopting the technology is not enough; it requires a thoughtful and intentional approach to truly realize its potential.

'I think it is revolutionary but it's also evolutionary and … to ignore it is a creative mistake for me. The main benefits is to allow you to work more like theatre producers …but if you don't take advantage of the opportunity to do things in real-time then the benefits aren't as clear'. Michela Ledwidge, Creative & Technical Director, Founder at Mod Studio.

Bertrand Polivka foresees a revolutionary impact from the implementation of Unreal Engine. He draws a parallel between its processes and 2D compositing, signifying a fusion of elements that transcends traditional methods. This optimism is founded on the conviction that real-time rendering will significantly expand the horizons of what is achievable in the industry.

'Yeah certainly... it's going to be a revolution. It's funny because it's almost like what I do in 2D... You take a girl on the green screen, a background, and some dust elements and combine them. Similarly, with metahumans, environments from Kitbash 3D, and atmospherics in Niagara, you combine all this... It's like comping 3D assets'. Bertrand Polivka, Lead Compositor at Cumulus VFX

In the evolving landscape of real-time rendering within the animation and film industry, a discernible strand of prudence tempers the prevailing enthusiasm. While the potential of real-time rendering is widely acknowledged, there is a concurrent awareness of its limitations and complexities. This cautious perspective is exemplified in the insights of several industry professionals.

Michela acknowledges the transformative impact of real-time rendering, particularly for smaller studios. However, she maintains that this technology does not markedly reduce the cost or duration of projects. This viewpoint suggests that while real-time rendering introduces novel opportunities, it does not inherently resolve all preexisting challenges within production processes.

'Oh look, it's been transformative because it allows a closer connection between creative and the result... you can see the result straight away. But like all complex systems, there's still a lot of learning to do. Not every creative can achieve results without large teams... For a small team, you typically need specialists in different areas, and it's rare to have one person who's across all of these areas'. Michela Ledwidge, Creative & Technical Director, Founder at Mod Studio.

Alex Weight adds another layer of caution. He posits that while real-time rendering engines hold the potential to redefine the industry, their impact on larger studios has been limited so far. This

cautious stance implies that, despite the promise of the technology, its comprehensive impact remains to be fully actualized.

> 'At the moment, it has a lot of attention... and everyone's excited about it. But I don't think it will have a big impact on the industry right now... It's been used successfully in shows like The Mandalorian and some Disney projects. Some studios are experimenting with it, but the biggest studios have tested it and decided it's not at the level needed for actual feature work yet... So I don't think it has a big impact on the big studios or the industry at this stage'. Alex Weight, Creative Lead at UTS Animal Logic Academy

Krista Jordan offers a historical perspective to temper expectations. She cautions against overconfidence in forecasting the trajectory of technological advancements, drawing parallels with past innovations like stereo cinema that failed to evolve as anticipated. This historical lens serves as a reminder that, while current applications of real-time rendering are promising, the future trajectory of this technology is not definitively predictable.

> 'I wouldn't want to predict the future... We can already see where real-time rendering is becoming beneficial. There are lots of experiences and things that can be done with real-time rendering that are useful and valuable... People said that about stereoscopic cinema, but it hasn't really gone very far because people aren't interested... We're still grappling with virtual reality and how that works in a tangible way in certain spaces'. Krista Jordan, Discipline Lead, AFTRS.

Statistical results of the survey

To further examine the implications of real-time rendering technology for the animation and film industry, an online survey was conducted, categorizing questions into two distinct groups: Attitudes

Table 1. Categorization of survey questions.

	Group 1	Group 2
Groups	Attitude towards adoption of real-time rendering technology	Real-time rendering technology trends
Question code	Q1: Perception of change in animation creation due to real-time rendering	Q4: Comparative image quality between real-time and traditional rendering
	Q2: Enables greater creative experimentation	Q6: Impact on cost
	Q3: Impact on work efficiency	Q7: Benefits towards smaller studios and independent artists
	Q5: Limitation due to distinct visual style	Q9: Changes in directors' narrative construction approach
	Q8: Integration difficulty into existing workflows	Q10: Influence on industry entry due to accessibility and affordability
	Q11: Requirement of specialist knowledge and training	Q12: Potential to replace traditional rendering methods
	Q14: Impact on the creative process	Q13: Disruption due to shift from linear to non-linear production pipelines
		Q15: Anticipation of using real-time technologies in future projects

towards the Adoption of Real-Time Rendering Technology, and Real-Time Rendering Technology Trends as shown in Table 1.

The intention is that combining the interview analysis with the quantitative data obtained from the survey will provide insights into the current state and future trajectory of real-time rendering technology in the industry. This combination of qualitative and quantitative methodologies provides a holistic view, capturing both the nuanced perspectives of industry practitioners and broader trends and attitudes within the field.

Demographic mapping. The online survey received 29 completed questionnaires. The demographics of the participants is shown in the table below.

It can be seen from the table that the participants are distributed across various roles and various studio types or organizations. Most participants have 1–3 years of experience, followed by those with more than 5 years of experience, indicating a mix of early-career and experienced professionals in the sample (Tables 2–4).

Correlation analysis within groups. The correlation matrix with p-value presented in Figure 1 provides an intricate map of the interrelated perceptions within two specified groups of survey questions. Values with p-values less than 0.05 are highlighted in bold in the figure. In Group 1, concerning Attitudes towards Adoption, there are noteworthy correlations among Q1 (perception of change in animation creation), Q2 (enabling of greater creative experimentation), and Q3 (impact on work efficiency). These correlations indicate that perceptions of change in animation creation, heightened creative experimentation, and improved work efficiency tend to co-occur among respondents. The correlation among these three aspects is frequently mentioned by the interviewees in the detailed interviews above. The application of real-time rendering technology greatly enhances work efficiency, which allows creators to conduct more creative experiments. This ultimately leads to changes in animation production. Similarly, Q11 (necessity for specialist knowledge) shows positive correlations with Q1, Q2, and Q3, suggesting a concomitant occurrence of the recognition of the need for specialized knowledge and training with positive experiences in animation creation, creative experimentation, and work efficiency. Their correlation can also be found in the detailed interviews above. As mentioned by Michela Ledwidge, the real-time rendering pipeline is fundamentally different from traditional animation production pipelines. Therefore, while it changes the traditional animation production process, it also requires creators to learn specialized knowledge. Additionally, Q14 (impact on the creative process) correlates moderately with Q1 and Q3, hinting at a simultaneous occurrence of these aspects with significant impacts on the creative process.

Table 2. Roles of the participants.

Role	Counts	Percentage (%)
Director	6	20.69
3D generalist	6	20.69
Other	5	17.24
Animator	4	13.79
VFX artist	4	13.79
Student	3	10.34
Cinematographer	1	3.45

Table 3. Studio types of the participants.

Studio Type	Counts	Percentage (%)
Independent studio	10	34.48
Educational institution	8	27.59
Freelancer	5	17.24
Large studio	5	17.24
Other	1	3.45

Within Group 2, designated as Trend and Future Perspective, a strong correlation is observed between Q9 (changes in directors' narrative construction approach) and Q10 (influence on industry entry due to accessibility and affordability). In the above interview, we may find the reasons for the observed correlations. Many interviewees believe that the accessibility and affordability of technology have led to its democratization. This democratization allows practitioners to experiment with different narrative approaches at a lower cost. This ultimately leads to changes in the existing narrative structures employed by directors. The interplay between Q10, Q12 (potential to replace traditional rendering methods), and Q13 (disruption from linear to non-linear production pipelines) indicates these aspects are typically experienced together, reflecting the intertwined nature of real-time rendering technology's influence on industry entry, its capacity to supplant traditional methods, and the disruption it introduces to established production workflows. The correlation between Q13 and Q15 (anticipation of utilizing real-time technologies in future projects) implies that those who perceive significant industry disruption due to production pipeline shifts also tend to be those anticipating a greater integration of real-time technologies in their future work.

Comparative analysis between groups. Figure 2 elucidates the correlations between two sets of survey questions, stratified into Group 1 and Group 2. The heatmap presents a correlation matrix that cross-examines the interrelationships between these groups. The survey data reveal that Q2 (Creative experimentation facilitated by real-time rendering) shares a substantial positive correlation with Q9 (Influence of real-time rendering on directors' narrative construction approaches). This suggests a concurrence among respondents that the advent of real-time rendering, which fosters creative experimentation, is concomitant with a transformation in directors' approaches to narrative structuring. Additionally, Q3 (Enhancements in work efficiency attributed to real-time rendering) is also strongly correlated with Q9, indicating a belief among respondents that the efficiency gains afforded by real-time rendering are influencing narrative construction methodologies in film and animation (or vice versa).

Moreover, Q14 (Influence of real-time rendering on the creative process) exhibits strong positive correlations with several Group 2 questions, notably Q9, Q10 (Democratization effect on industry

Table 4. Experience level of the participants.

Experience Level	Counts	Percentage (%)
1–3 years	11	37.93
More than 5 years	8	27.59
More than 3 but less than 5 years	7	24.14
Less than 1 year	3	10.34

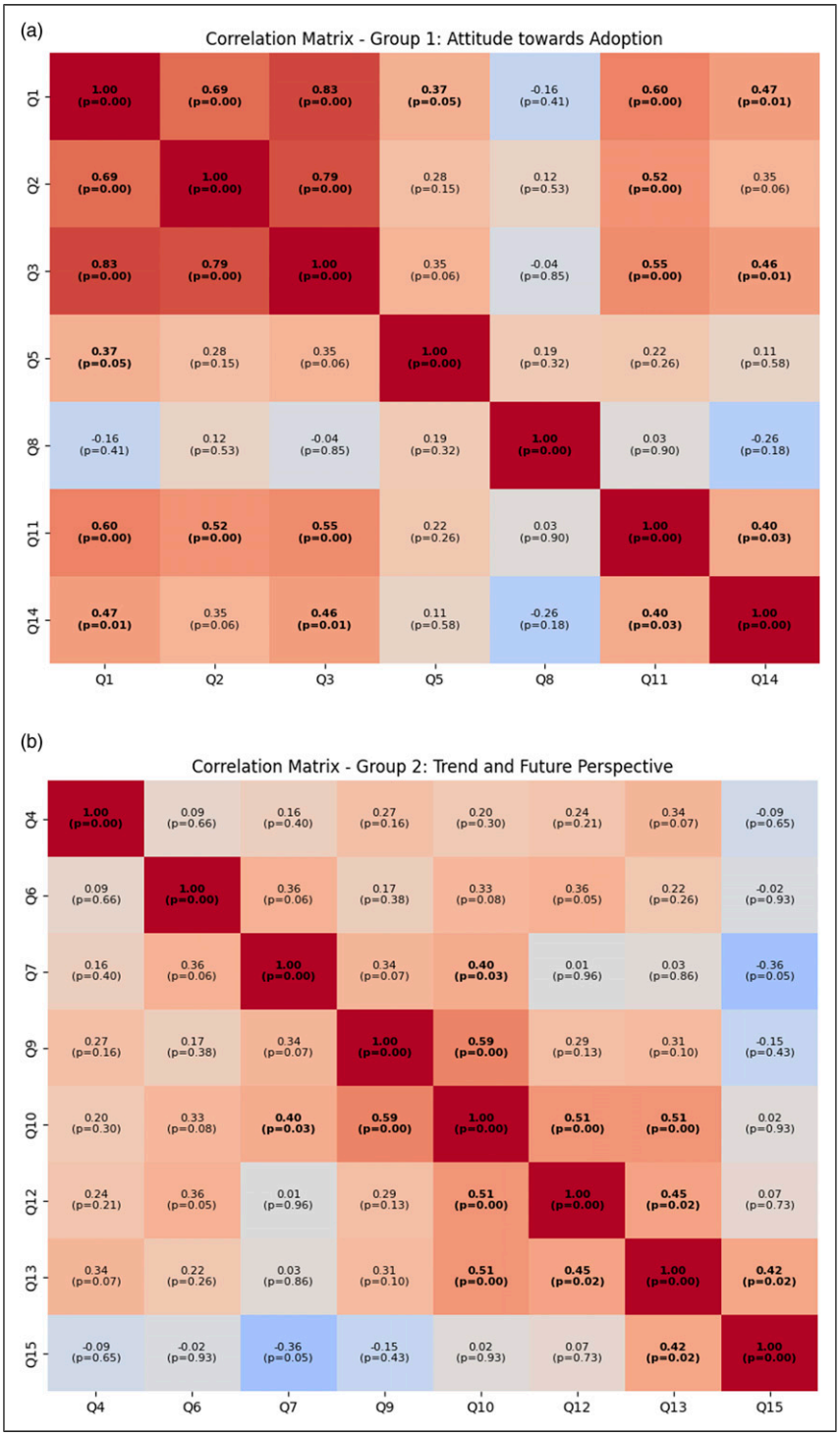

Figure 1. The heatmap of correlation matrix within groups: (1a) Correlation matrix of group 1; (1b) Correlation Matrix of group 2.

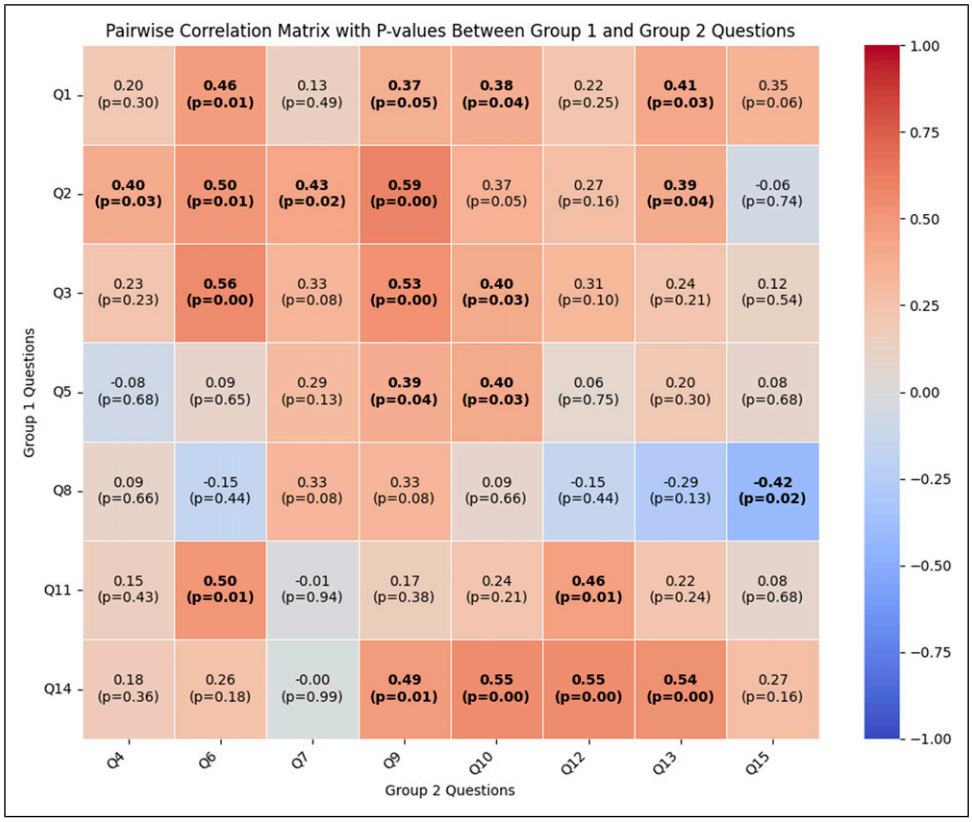

Figure 2. The heatmap of correlation matrix between groups.

entry), Q12 (Real-time rendering's potential as a replacement for traditional methods), and Q13 (Transition from linear to non-linear production pipelines). This pattern indicates that respondents who perceive a significant impact of real-time rendering on the creative process also acknowledge its broader implications across various industry facets, ranging from narrative construction to the reconfiguration of production pipelines and the potential supplanting of traditional rendering techniques.

A moderate positive correlation is observed between Q1 (Alterations in animation creation processes) and Q13, suggesting an association between respondents' experiences of change in their animation creation processes due to real-time rendering and the recognition of a paradigm shift from linear to non-linear production pipelines. Conversely, Q8 (Challenges in integrating real-time rendering into existing workflows) negatively correlates with Q15 (Prospective utilization of real-time technologies in future endeavors), implying that those respondents who encounter difficulties in assimilating real-time rendering into their current practices may be less inclined to incorporate such technologies in their prospective projects (or vice versa). Q5 (Distinctive visual aesthetic attributed to real-time rendering engines) demonstrates only weak correlations with the Group 2 questions, implying that the unique visual style of real-time rendering engines may not substantially influence the broader aspects of content creation or the industry's directional course. Lastly, Q11 (Requirement for specialist knowledge and training) positively correlates with Q12, suggesting that respondents

who foresee the capacity of real-time rendering to supplant traditional methods also recognize the necessity for specialized education to fully leverage the capabilities of this emergent technology.

Summary of qualitative insights and quantitative correlations. The synthesis of qualitative insights and quantitative correlations provides a multifaceted understanding of real-time rendering technology's impact on the animation and film industry. Firstly, enhanced creative experimentation and efficiency emerge as significant benefits, with real-time rendering allowing for immediate feedback and iterative improvements, thus boosting work efficiency and fostering creative processes. This finding is corroborated by strong correlations in survey data among changes in animation creation, creative experimentation, and improved work efficiency. Secondly, participant perceptions that real-time technologies provide for the democratization of technology is evident, as real-time rendering makes high-quality tools accessible to smaller studios and independent creators, thereby broadening industry participation. This democratizing effect aligns with quantitative correlations showing changes in directors' narrative approaches due to increased accessibility and affordability. Despite the optimism, there is notable resistance to change, primarily due to integration challenges with existing workflows, which is reflected in the negative correlation between integration difficulties and future use anticipation. Nevertheless, there is cautious optimism for the future, with many professionals recognizing the technology's disruptive potential and anticipating its use in future projects. Additionally, real-time rendering impacts narrative construction by enabling directors to experiment with new techniques, supported by strong correlations between narrative changes and industry democratization. The need for specialized training is emphasized, as the technology demands new skills, a fact underscored by correlations linking specialized knowledge with positive creative outcomes. While there is potential for real-time rendering to replace traditional methods, this transition is still ongoing, indicated by correlations between traditional method replacement and the need for training. Lastly, the shift to non-linear production pipelines facilitated by real-time rendering enhances collaboration and flexibility, as shown by correlations between changes in animation creation and the move to non-linear workflows. These integrated findings provide a comprehensive view of real-time rendering's transformative yet challenging role in the industry.

Discussion

Comparative focus: Large studios versus independent studios in real-time rendering adoption. While the primary dataset for this research was collected through interviews and surveys largely involving independent studios and freelance creators – due to the accessibility constraints and community-based recruitment methods, we acknowledge the resulting sample skew. To mitigate this limitation and ensure broader contextual relevance, we supplement our analysis with secondary data from publicly available industry reports and case studies. Epic Games' Animation Field Guide (2022) (Bousquet, 2022) includes first-hand insights from large-scale production houses such as Sony Pictures Imageworks, BRON Studios, Spire Animation Studios, and DNEG. These cases document how leading studios are integrating real-time rendering into their pipelines. From the interview we can see that these studios prioritize pipeline scalability, cross-departmental integration and commercial efficiency.

For example, Sony Pictures Imageworks deliberately constructed a sandbox production environment for their *Love, Death & Robots* episode In Vaulted Halls Entombed, keeping it separate from their 25-year-old legacy pipeline to ensure system reliability and artist workflow consistency. Spire Animation Studios restructured their team model into multidisciplinary 'pods', allowing lighting, modeling, and layout to occur in parallel within Unreal Engine, thereby promoting creative convergence and minimizing communication overhead. BRON Studios adopted what they call a 'live-action approach to animation',

leveraging Unreal Engine to accelerate iteration and enable globally distributed teams to collaborate synchronously. Their focus extended beyond creative control to IP scalability, with assets reused across animation, interactive media, and metaverse initiatives.

These differences underscore a fundamental insight: real-time rendering is a flexible infrastructure that serves divergent strategic objectives depending on team scale and production context. For large studios, it is a tool of transformation; for small teams, it lies in cost efficiency and tool democratization. This divergence suggests future research should explore the 'reverse diffusion' of innovation – how agile practices pioneered by small studios influence institutional workflows – as well as the role of intermediary platforms like Unreal Engine in shaping convergent production ecologies.

The paradigm shift towards non-linear convergence workflows. The transition from linear to non-linear production processes observed in the uptake of real-time rendering technologies represents more than a technical optimization – it signals a fundamental paradigm shift in how creative work is conceptualized, coordinated, and executed in the film and animation industries. Drawing from the field of Production Studies (Mayer et al., 2009), which emphasizes the socio-institutional effects of media technologies, our findings suggest that real-time rendering restructures not only workflow sequences but also labor divisions, professional boundaries, and creative hierarchies.

To describe this emergent structure, we propose the concept of a non-linear convergence workflow. This term captures a production paradigm in which technological and creative processes converge in real-time, and the input from artists, technicians, and directors is coordinated through simultaneous, rather than sequential, collaboration. Unlike conventional models where decisions cascade down a rigid pipeline, non-linear convergence allows for dynamic feedback loops, enabling teams to make aesthetic, narrative, and technical adjustments in the moment. This model redefines creative agency across roles and opens up possibilities for more integrated and responsive production cultures.

By articulating this paradigm shift through the lens of convergence and post-Fordist flexibility, our study contributes a theoretical vocabulary to ongoing discussions about the changing nature of media labor and creative practice in technologically mediated environments.

Rethinking democratization in real-time rendering. While real-time rendering platforms such as Unreal Engine have become more accessible and even free for independent creators and small studios, the notion of 'democratization' warrants a more critical examination. In this context, democratization should not be equated simply with the availability of tools, but rather interrogated in terms of accessibility, usability, and agency.

Drawing from feminist technology studies, Wajcman (Wajcman, 2007) argues that technologies are embedded within existing social hierarchies and that access must be understood as relational and contingent. From this perspective, democratization is not only about possessing the tools, but about having the structural and cultural capacity to meaningfully participate in their use. Similarly, Lisa Nakamura (Cruikshank, 2010) highlights how narratives of digital empowerment often overlook the uneven distribution of labor, knowledge, and representation across gendered and racialized lines. These observations are further supported by Erhart et al.'s chapter Lost in the Virtual Abyss in The Screens of Virtual Production which critically examines gendered participation in the Australian VP sector (Erhart et al., 2025). Drawing on interviews with twelve women and gender-diverse practitioners, the authors highlight persistent structural inequalities – including underrepresentation in technical roles, assumptions about women's technical incapacity, and the disproportionately male composition of VP educators and mentors. While our study did not set out to examine gender dynamics, we incidentally observed a similar pattern in our own interviews. Of the fifteen participants, only two were women, and among the twelve participants based in Australia, ten identified

as male. This imbalance was not the result of selection criteria, as participants were nominated by studios and institutions we contacted via email. Given the small and non-representative nature of our sample, we do not claim this as a definitive finding. Rather, we see it as a suggestive observation that may align with Erhart et al.'s broader conclusions (Erhart et al., 2025), and one that highlights the importance of further research into structural exclusions in technology democratization.

Our interviews and survey responses align with these critiques. Participants with 1–3 years of experience demonstrated the highest average agreement that real-time rendering represents both a major technological shift (Q12) and a significant impact on the industry (Q1). Meanwhile, participants with over 5 years of experience also recognized the industry-wide impact (Q1) with the highest average rating, though their view of it as a 'revolutionary change' (Q12) was slightly more reserved. In contrast, participants with less than 1 year or 3–5 years of experience showed lower levels of enthusiasm toward real-time rendering. Notably, the 3–5 year group rated the 'transformative' nature of the technology (Q12) the lowest among all subgroups. We interpret this as a sign of transitional hesitation – these practitioners may already be invested in traditional pipelines but have not yet fully adapted to real-time workflows. While newcomers expressed strong optimism about the future of real-time rendering – often perceiving its low-cost and flexible architecture as empowering – more experienced practitioners, particularly those trained in traditional filmmaking, often resisted adopting new tools. They cited difficulties with shifting from shot-based to level-based thinking, a discomfort with game-engine logic, and a perceived mismatch between new tools and existing creative mental models. In other words, prior experience in the industry can sometimes act as a constraint, reinforcing the idea that real-time rendering may, paradoxically, be more democratizing for 'newcomers' than for incumbents.

In the meantime, there is a tension between democratizing content creation and maintaining standards of quality. Future studies could explore how creators, platforms, and audiences respond to the challenge of navigating quality in an oversaturated media environment. Comparative research might examine how different industries (e.g., gaming, film, short-form video) have developed decentralized or community-driven quality assessment mechanisms – such as peer recognition systems, platform-based reputation metrics, or algorithmic curation – and evaluate their implications for visibility, recognition, and equity.

Additionally, scholars may consider how the values of craftsmanship, originality, and narrative depth are evolving in contexts where tools are universally available but creative expertise varies widely. Understanding how excellence is identified, supported, and sustained in a democratized creative ecosystem will be essential for shaping future cultural infrastructures that are both inclusive and aspirational. This line of inquiry could also inform the design of more participatory and transparent quality frameworks, which uphold creative standards without compromising open access – ensuring that democratization does not come at the cost of critical discernment.

Therefore, we think the current moment not as a wholesale democratization, but rather as a form of 'differentiated enablement' – where technological access is unevenly distributed, and its full benefits accrue primarily to those who are structurally and cognitively positioned to embrace new paradigms. This framing better captures the complex sociotechnical landscape of contemporary screen production.

Conclusion

Real-time rendering technology and virtual production tools appear to be driving a shift towards dynamic, non-linear production methods. This transformative shift is characterized by increased production speed and efficiency, while also presenting new technical challenges and a need for

specialist knowledge in these areas. The research findings, derived from both interviews and surveys, reflect a predominantly positive reception among practitioners towards real-time rendering. They acknowledge its capacity to invigorate the creative process and optimize workflow efficiency. Moreover, these insights underscore the technology's profound impact on industry accessibility, creative practices, and narrative construction, marking a departure from technical enhancements to affecting the essence of filmmaking.

The democratization of technology, a prominent theme throughout the research, encapsulates the process by which filmmaking tools, techniques, and platforms are becoming increasingly accessible, thus broadening participation in the industry. This shift towards democratization is largely driven by the accessibility and affordability of real-time rendering engines, which are breaking down traditional barriers and enabling a diversity of creators to realize their visions without prohibitive costs.

However, this process is not without contradictions. While the early sections of this paper highlight the democratic potential of real-time rendering, our analysis also reveals structural and operational barriers – such as resistance to change, steep learning curves, and upstream workload intensification – that complicate this narrative. Rather than being a contradiction, we argue that these opposing forces coexist and must be understood as part of the same transformation. Real-time rendering democratizes possibilities more than outcomes: it opens up who can participate in high-quality content creation, but it does not guarantee success, ease, or equal adoption across the board. For experienced professionals, ingrained workflows and role-specific expertise may create resistance or inertia; for newcomers – particularly students or early-career practitioners – lack of legacy constraints often makes real-time workflows more intuitive and appealing.

Thus, we recognize this dynamic tension: the democratizing potential of real-time rendering is real, but conditional and uneven. It is shaped by sociotechnical configurations, professional cultures, and individual positionality within the media ecosystem. This nuance offers a more accurate and grounded understanding of how digital production technologies are reshaping creative labor and participation.

Looking ahead, it appears likely that the industry will progressively pivot towards non-linear production pipelines, a transformation substantiated by the proclivity for real-time rendering. This shift will impact project conceptualization, execution, and delivery mechanisms. Future scholarly work should continue to explore these impacts, focusing particularly on longitudinal studies that can provide insight into the enduring effects of real-time rendering on creative outputs and industry standards.

Future research should also investigate the ongoing debate over whether real-time rendering is a genuinely 'revolutionary' force or just another technique which will be incorporated into the industry's technological repertoire. This includes examining the technology's scalability for large-scale productions, its integration with traditional filmmaking techniques, and its long-term impact on the workforce. Additionally, there is a need for rigorous analysis of the pedagogical approaches within educational institutions, ensuring that emerging talent is equipped with the skills to navigate and shape the future of this rapidly evolving digital landscape.

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Ethical considerations

The University of Technology Sydney Human Research Ethics Committee at University of Technology Sydney approved our interviews (approval: UTS HREC ETH19-3452) on November 18, 2022. Respondents gave written consent for review and signature before starting interviews.

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Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author, Xuguang Jia.

Supplemental Material

Supplemental material for this article is available online.

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