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REGULAR PAPER

Exploring the impact of volumetric graphics on the engagement of broadcast media professionals

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Abstract

The purpose of this study is to explore content creator preferences in broadcast media, with a specific focus on the impact of integrating 3D graphics to enhance viewer engagement. In this study, we investigated the integration of 3D technology in broadcasting. We examined the preferences of content creators and assessed the impact of 3D photo-real human representations on perceived production quality and viewer engagement. Data was collected through surveys, interviews, and real-time broadcast analysis to gain insights into this technology's potential benefits and challenges in broadcasting. Our findings indicate that incorporating 3D photo-real human representations into broadcasting significantly improves production quality and viewer engagement, especially in real-time broadcasts. We also observed that 3D humans offer greater depth and presence, although challenges in fidelity and orientation highlight areas for technological advancement. Additionally, our study revealed the complementary nature of 2D and 3D visuals in broadcasting, with each modality serving distinct purposes-2D for clarity and information conveyance and 3D for immersive experiences. This research suggests a paradigm shift in broadcast content creation, where integrating 3D technologies, such as 3D photo-real human representations, can lead to more dynamic, engaging, and visually appealing content across various platforms. The study's findings provide explicit guidelines for content creation, catering to diverse viewer preferences and evolving consumption patterns. This research contributes to the broader understanding of how technological advancements in extended reality can effectively enhance the media landscape.

Keywords Extended reality · 3D visuals · Graphics · Content creator perspectives · Broadcast media

1 Introduction

How do you consume your media? In the twenty-first century, many technologies have developed and increased extensively for multimedia content creation alongside consumption. Modern broadcast systems have evolved significantly, incorporating novel technologies and digital workflows to deliver audio and video content to a broad audience [1]. The influence of dynamic visualizations, such as 3D models and animations, has been shown to significantly increase intrinsic motivation for learning in educational settings, suggesting potential benefits in broader multimedia and broadcast applications [2]. Furthermore, the evolution of broadcast graphics, including 3D visuals, AR, and AI-based object tracking, has significantly enhanced viewer engagement and storytelling [3].

Broadcasters strive to engage viewers by incorporating interactive features and personalization [4]. Simultaneous multi-platform access to news media raises issues with the

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effectiveness of multi-platform content distribution [5, 6]. As such, our research explores how 3D media impacts perceived audience reach and engagement for broadcast media professionals. Recent studies in media multitasking provide valuable insights into how audiences engage with multiple media platforms, which is highly relevant to understanding the dynamics of multi-platform broadcasting [7]. The broadcast industry continuously evolves, and new technologies and standards emerge and disappear, shaping how content is produced, delivered, and consumed.

Persistent 3D worlds, also problematically known as "*metaverse*" [8], are starting to be introduced to broadcast content creation pipelines via extended reality (XR) technologies. XR technology is an umbrella term for virtual, augmented, and mixed reality (VR/AR/MR) technology that merges the physical and virtual worlds to create a combined interactive environment [9]. It enables users to experience and interact with digital content and virtual objects in real-time within their physical surroundings [10]. Unlike VR, which completely immerses users in a virtual environment [11], and AR, which overlays digital elements onto the real world [12], MR integrates virtual objects seamlessly into the user's physical environment [13], allowing for more immersive and interactive experiences [14]. These types of technology typically involve specialized devices, such as head-mounted displays (HMDs), with sensors, cameras, and displays [9, 15].

XR, combined with AI, has the potential to play a significant role in modern broadcast systems, particularly in introducing new visual elements to the physical studio [16]. In this paper, we are specifically interested in determining if XR content creation tools can be integrated into existing 2D broadcast pipelines [17]. For example, sports broadcasts can overlay virtual graphics on the field or court, displaying real-time player stats, visualizing tactics, or highlighting key moments [18]. Instead of physical sets, broadcasters can employ virtual environments generated through XR technology [19, 20]. This technique can give viewers a richer understanding of the game and enhance their enjoyment [21]. It also offers greater flexibility and cost-efficiency, as virtual sets and mobile technology can be easily customized, changed, and transported to different locations, eliminating the need for elaborate physical setups [22].

XR technology can also facilitate remote production, where broadcasters can remotely access virtual production environments, interact with virtual objects, and collaborate with remote teams [23, 24]. This remote working potential enables more efficient and cost-effective production, reducing the need for physical presence [25]. This also opens up new possibilities for advertising and sponsorship integration. Virtual objects or characters can be seamlessly integrated into broadcast content, providing targeted and interactive advertising experiences [26, 27].

Real-time broadcast production often incorporates 2D XR technology to display on-screen graphics, particularly in sports broadcasts [28, 29]. While 2D graphics serve their purpose, there is great potential in utilizing high-definition and highly functional 3D assets to create a more immersive and informative visual experience for audiences [30]. However, a significant challenge arises when incorporating live-action content, such as player characters, as they are typically only available in 2D format [31]. This limitation of 2D content poses a challenge in the inherently 3D world of XR [32].

Traditional methods of creating 3D content with any visual quality tend to be complex and expensive, making them ill-suited for the fast-paced nature of live broadcasting. The workflow, planning, turnaround time, and logistics associated with standard 3D content creation are often too slow to meet the real-time demands of broadcasting [33]. Fortunately, recent advancements in AI have enabled users to generate 3D content quickly and efficiently using mobile technology without requiring specialized studios or extensive resources [34]. AI-powered tools enable accelerated 3D content creation, addressing the limitations of traditional 3D reconstruction methods [35]. However, it is essential to note that the visual quality achieved through single-camera AI-driven approaches may have some restrictions, including artifacts and inaccuracies in backside reconstruction [36].

To overcome this challenge, a new approach to volumetric reconstruction of 3D photoreal human representations is presented and explored that applies technology pioneered by Volograms,[1] which involves transforming 2D imagery of live-action content into a 3D reconstruction of a moving person. This technique holds promise in creating live-action content that aligns with the 3D nature of XR, thus enhancing the overall production quality [37, 38]. This study aims to formally compare these two content creation pipelines from the standpoint of both end users (audiences and media enthusiasts) and advanced users (the teams creating broadcast content) to examine the potential of 2D and 3D human representations in real-time XR broadcast production. By evaluating the benefits and drawbacks of each approach, this research seeks to provide valuable insights into the optimal utilization of 2D and 3D technologies to enhance the overall production quality of XR broadcast content creation workflows [10, 39].

In this manuscript, we aim to address the following research questions to advance our understanding of volumetric on-screen graphics in the engagement of broadcast media professionals.

[1] https://www.volograms.com/.

1. How does integrating XR technology into traditional broadcasting pipelines impact the production quality and viewer engagement in real-time broadcasts?
2. What are the benefits and limitations of using 2D versus 3D content creation approaches in XR broadcast production, particularly regarding audience reach and engagement?
3. To what extent can recent advancements in AI and volumetric reconstruction techniques address the challenges of integrating live-action content in XR broadcasting?
4. How does using XR technologies in broadcasting influence the efficiency and cost-effectiveness of production workflows, particularly in remote production settings?
5. What are the implications of XR and AI integration for multi-platform content distribution, especially regarding interactivity and viewer experience?

2 Background

The evolution of video technology has significantly impacted media production and consumption. Advancements in display technology, content availability, and interactive experiences have driven this evolution [40]. The shift from traditional broadcasting to on-demand content consumption, enabled by broadband connectivity, has led to new content formats like 4 K and 8 K and emerging technologies such as AR/VR/MR [41]. The Internet's accessibility to the media industry has created opportunities for innovation across the entire value chain [42]. This has resulted in a complex ecosystem of connected devices, people, and narratives, transforming television from a controlled broadcast platform to an interactive, multimodal experience [43]. These developments have introduced challenges in storytelling, content management, and distribution while necessitating new skills for professional producers to incorporate user-generated content [43].

VV is emerging as a revolutionary medium for creating immersive and interactive experiences in XR environments [44]. This technology enables the capture and reconstruction of real-world scenes and objects in 3D, allowing viewers to interact with content from any perspective [44, 45]. Recent advancements have focused on enhancing interactivity, with researchers developing methods for blending volumetric clips, skeletonizing captures, and applying multi-bone retargeting to create responsive digital humans [46]. Additionally, deep learning techniques are being employed to transform 2D archival images into volumetric 3D assets for VR and AR applications [47]. Cloud-based rendering systems are also being developed to address the high processing requirements of interactive volumetric content, enabling real-time streaming and rendering [48]. These innovations are poised to redefine content creation and consumption paradigms across various industries.

Creating XR content for broadcasting involves multiple components and processes: content creation, camera tracking, green screen extraction, object tracking, compositing, rendering, and delivery, see Fig. 1. While 3D models and animations are ideal, many productions still rely on 2D content positioned in 3D space due to the complexity of creating realistic 3D assets [49]. Recent advancements have improved the integration of virtual and real objects in professional studios, enabling features like shadow casting and occlusion through RGB and depth cameras [50]. AR has been proposed to bridge the gap between physical and virtual production environments, supporting character animation by superimposing 3D graphics on real-world objects [51]. As XR technology evolves, there is growing interest in introducing real-time 3D pipelines across various media industries, from entertainment to studio set design [49].

The first step in a real-time XR pipeline is creating the virtual content, such as 3D models, animations, and effects, that will be overlaid onto the live footage. However, most of the content in broadcast productions today is 2D content positioned in the 3D space as a billboard (i.e., the content moves with the camera so it is always facing it). This method is used because creating realistic 3D models and animations is a complex task that involves understanding the principles of 3D graphics and animation, requires the use of 3D modeling and animation software, specialized professionals with training, or needs to be obtained from existing libraries [52, 53].

Accurate camera tracking ensures virtual elements align correctly with the real-world scene. There are different methods for camera tracking, including optical tracking

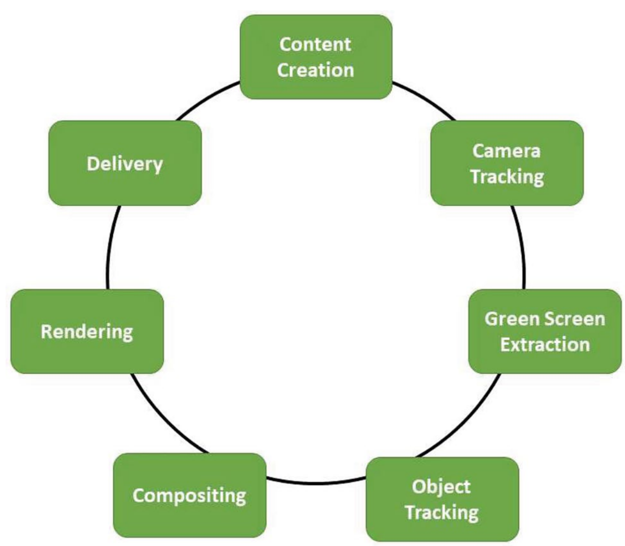

Fig. 1 A traditional XR content creation pipeline

systems, sensor-based monitoring, or even computer vision techniques to track features in the live footage. Optical tracking systems are highly accurate and commonly used in professional settings [54]. Sensor-based systems utilize gyroscopes, accelerometers, and other sensors to determine camera position and orientation [55]. Computer vision techniques can offer a cost-effective solution by analyzing visual data to track camera movement [56].

In many live studio broadcasts, a green screen separates the foreground subject(s) from the background. Chroma keying techniques are then used to extract the green background and replace it with the virtual environment. This process is critical for ensuring a seamless blend between the real and virtual elements [57]. Object tracking is also essential, especially when interaction with virtual elements is involved. Motion capture systems, fiducial markers, or computer vision algorithms can be used. Motion capture systems provide high accuracy but require specialized equipment [58, 59].

The next stage involves blending real-world footage with virtual elements. This process, known as compositing, requires accurately placing the virtual objects within the scene and ensuring realistic lighting, shadows, and reflections. Compositing is a crucial step in determining the final visual quality of the XR content [60]. Real-time compositing software or game engines are often used to achieve this, with game engines providing more interactive capabilities [61, 62].

The final output must be rendered in real-time once the virtual elements are composited with the live footage. This step involves generating the combined frames or video stream, accounting for lighting and shading effects, and ensuring smooth playback at the desired frame rate. Real-time rendering is challenging due to the high computational requirements needed to achieve realistic visuals [63, 64].

Finally, the rendered output is then delivered to various platforms for distribution, such as television broadcasts, streaming services, or online platforms. Providing high-quality XR content over different platforms poses unique challenges related to bandwidth, compatibility, and interactivity [65, 66]. The final content can then be transmitted in real-time to provide an interactive viewing experience for the audience, which increasingly demands more engaging and immersive content [17, 67].

VV represents a significant advancement in media production, offering new possibilities for immersive and interactive experiences in AR/VR/MR [44, 68]. This technology enables the creation of high-quality 3D models of real people, capturing facial expressions and clothing details with unprecedented accuracy [68]. Specialized studios equipped with multiple cameras and lighting systems facilitate the capture process, allowing for 360-degree acquisition and automatic processing [68]. The resulting content can be viewed from any angle, enhancing audience engagement in XR applications [44]. Recent developments have also introduced interactive capabilities, enabling real-time animation and streaming of volumetric video content [48]. As technology progresses, it opens up new avenues for storytelling and human representation in virtual environments, transforming how audiences interact with digital media [69].

While promising immersive experiences, VV faces significant challenges in production and streaming. The sheer volume of data necessitates advancements in compression and streaming technologies to overcome bandwidth limitations and device processing constraints [70, 71]. Researchers are exploring various approaches to optimize volumetric content delivery, including compression solutions, network adaptation, and user-adaptive streaming for high-end and low-powered devices [72]. Advanced capture systems, such as Fraunhofer HHI's 3D Human Body Reconstruction technology, are being developed to create high-quality, naturally moving 3D models for virtual and augmented reality applications [68]. Visual fidelity, latency, and content security remain challenging despite these advancements.

This paper aims to comprehensively understand volumetric reconstruction's role in modern media production, offering insights into its current applications and future possibilities. By embracing these technological advancements, the industry can unlock new dimensions of storytelling and audience engagement in broadcasting and beyond. We will show how AI techniques can help generate photorealistic 3D models from the existing footage the broadcasters already have: studio photos and videos of athletes, in-game shots, and other media captured in uncontrolled environments. These 3D models, different from the traditional 2D billboards used in broadcasts, behave more naturally in 3D environments where the camera moves freely in space. Furthermore, they can cast virtual shadows on the floor and be used to match the lighting conditions of the studio, which can improve immersion quite significantly. This 2D-to-3D conversion tool is designed to integrate within the broadcaster's creative pipeline, opening various creative options.

3 Methodology

This study employed a mixed-methods approach to explore real-time content creation for live studio broadcasts, focusing on the perspectives of technical staff producing broadcast content, the broader media industry, and technically competent audiences. Thus, a purposive sampling technique was used to recruit participants. A call for voluntary participation was issued via internal and external media networks and social media platforms to reach a diverse group of industry professionals and technologically savvy individuals [73].

Fig. 2 Screenshot of 3D volumetric model (left) and 2D image (right)

Participants were presented with 2D vs. 3D content examples to explore user attitudes toward the content; see Figs. 2 and 3.[2] This demonstration aimed to provide a tangible comparison between the two formats. Following the technology demonstration, participants were invited to complete an online questionnaire. The questionnaire design was informed by principles of user experience research and cognitive psychology to ensure the clarity and relevance of the questions [74].

The questionnaire began with a demographics section, capturing user-type data per the Nielsen user cube methodology [75] and categorizing users based on their technology use and familiarity. Participants identified as novice users were excluded to maintain the study's focus on professional and technology-aware users.

The main section of the questionnaire consisted of nine open-ended questions, as listed. These questions were designed to elicit detailed responses on the participants' attitudes and preferences regarding 2D and 3D content in broadcasting. The qualitative data was analyzed using thematic analysis to identify the patterns, themes, and meanings of participant responses [76]. This approach allows for a nuanced understanding of the subjective experiences and perceptions of the participants.

In addition to qualitative analysis, statistical methods were employed to analyze demographic data and any quantifiable responses to the questionnaire. Descriptive statistics were used to summarize demographic information, and inferential statistics were applied to examine any significant differences in attitudes between different user types [77].

[2] https://youtu.be/KP-trlRw2Is?si=BjnqTvhAuCkrnKia.

The study was conducted per ethical guidelines for the University, adhering to the requirements for human subjects research. Participants were informed about the purpose of the study, and their consent was obtained before participation. Confidentiality and anonymity of the participants were maintained throughout the research process [78].

The questions delivered were as follows:

1. What did you like the most and the least about the content you just watched? Which did you prefer? Why?
2. Did you notice the difference between the sports players displayed while viewing the videos? Could you describe the differences?
3. According to you, which version had the most influential displays and the most substantial impact on your viewing experience?
4. Do the signage and graphics on-screen compel you to watch a show? Why or why not?
5. Would you watch a particular show because of the on-screen images or stats?
6. Do you think this video format could be applied to specific TV Shows? If so, what other TV shows would it be suited for?
7. Does using enhanced production tools, such as 3D, add to the production value of a show? If so, can you describe or explain how it does?
8. If these types of 3D assets were available to download for personal use, could you think of using them for anything?
9. Would you like to create a personal 3D avatar? What would you use it for and why?

3.1 Participants

This study analyzed responses from 90 participants. After excluding novice respondents, 67 media enthusiasts and professionals contributed valuable insights. The sample comprised 36 males, 30 females, and one non-binary individual. The mean age of participants was 28.45, with a standard deviation (SD) of 8.87 (see Table 1). Professional roles within the media industry were reported as follows: media professionals (n = 26), encompassing researchers, creative directors, broadcast engineers/technicians, etc., and media enthusiasts (n = 41), including students, graduates, interns, assistants, runners, etc.

When evaluating their proficiency in using digital technology for media entertainment, participants rated themselves, on average, as "Very Good" or "Excellent" (M = 6.21; SD = 0.95). Their familiarity with technologies used in media entertainment was described as "Very Familiar" or "Extremely Familiar" (M = 6.25; SD = 0.94). Regarding their expertise in using media technology for content creation, participants identified as "Average" or "Above

Fig. 3 Screenshot of 2D (left) versus 3D (right) broadcast content

Average" (M = 4.58; SD = 1.65). As Fig. 4 illustrates, these parameters facilitated categorizing participants' user types within a user cube framework. Consequently, our sample was classified into two primary groups: advanced users (n = 40) and end users (n = 27).

4 Results

In analyzing the data, we employed thematic analysis [79], a method widely recognized for identifying patterns and themes within textual datasets. The process involved systematically examining the participants' responses, facilitated using MaxQDA software for qualitative data analysis. This approach enabled us to generate initial codes and subsequently group them into themes (see Fig. 5). Through iterative rounds of review and refinement, we defined and named the core themes, ultimately constructing a narrative that captured vital insights and perspectives from the data. This method was instrumental in revealing nuanced understandings of the participants' views on standard 2D versus 3D volumetric assets in broadcasting. In the following sections, we explore the most frequently mentioned core themes.

Table 1 Participant demographics

Demographic	Value
Total Participants	90
Excluded Novice Respondents	23
Final Sample	67
Gender	
- Male	36
- Female	30
- Non-binary	1
Age	
Mean	28.45
Standard Deviation	8.87
Ethnicity	
- Irish	14
- Other White	14
- Chinese or East Asian	14
- Indian or South Asian	13
- Other	12

4.1 Immersion and realism

The first major theme from the data was the enhanced immersion and realism provided by 3D representations compared to 2D. Both advanced and end-user groups recognized the merits of 3D visuals in creating a more realistic and depth-enhanced viewing experience. Participants appreciated the immersive quality of 3D models, noting how they contributed to a sense of presence and engagement with the content.

Advanced group participants emphasized the technical aspects, such as lighting, shadow, and model quality, which contributed to the realism of 3D visuals. They noted that these elements made the viewing experience more lifelike and captivating. However, some participants also mentioned issues with camera tracking, where excessive movements caused discomfort. On the other hand, the end-user group highlighted the dynamic and engaging nature of 3D visuals, appreciating how these elements added vitality to the broadcast. They focused less on technical details and more on the overall visual impact.

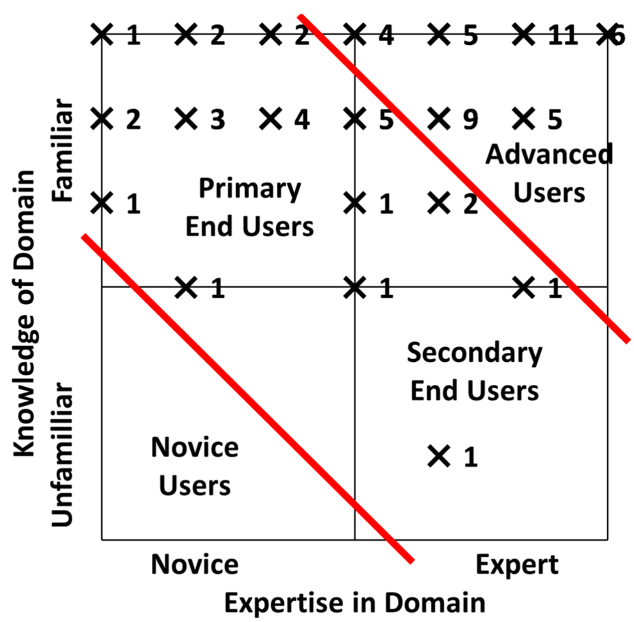

Fig. 4 User cube describing the cohort user types (the red line indicates group division with novice users removed)

Theme	Sub-theme	Interpretive Meaning
Immersion and Realism	Depth and Presence	• Appreciation of 3D models' realism
		• Increased sense of presence and engagement
	Technical Concerns	• Lighting, shadow, and model quality
		• Issues with camera tracking and movement
Merits of 2D and 3D Visuals	Strengths and Weaknesses	• 2D: Clarity and straightforward interpretability
		• 3D: Immersive and realistic properties
	Contextual Preferences	• Influence of presentation context on preference
		• Technical feedback vs. overall impact for end-users
Impact on Viewer Engagement	Interactive and Immersive Experiences	• Enhanced engagement with 3D models
		• Attention-grabbing features of 3D visuals
	Novelty and Substantial Impact	• Perceived novelty of 3D displays
		• Comparison with traditional formats
Role of Graphics and Visuals	Professional and Informational Impact	• Contribution to professionalism and quality
		• Functional role in conveying information
	Immersive and Informative Qualities	• Enhancing content comprehension
		• Potential of interactive graphics and AR
Enhancing Content	Understanding and Engagement	• On-screen visuals for dynamic programs
		• Contribution to production values and appeal
	Influence on Viewing Decisions	• Not primary motivator but influential
Applications in Different Genres	Suitability for Various Genres	• Sports: Enhancement of commentary and stats
		• Educational content and documentaries
		• News: Aid in visualizing data and concepts
Enhanced Tools and Their Impact	Augmenting Viewer Immersion	• Lifelong viewing experience with 3D tech
	Improving Production Value	• Polished look and higher budget impression
		• Sports broadcasting and medical education
Personal Avatars	Creative and Pragmatic Applications	• Creative content creation, video games, AR
	Visualization and Entertainment	• Use in visualization, entertainment, education
	Interactions and Engagement	• Personal 3D avatars for meetings and profiles
Efficiency and Cost-Effectiveness	Streamlining Production	• Efficiency and cost-effectiveness in production
		• Agility in modern broadcasting workflows
Implications	Interactivity and Viewer Experience	• Broadening appeal and engagement on platforms
	Media Consumption Trends	• Adapting to shifting consumer preferences

Fig. 5 A three-tier representation of the qualitative themes and sub-themes in order of participant frequency of mentions

4.2 Comparative merits of 2D and 3D visuals

Another significant theme was the comparative analysis of 2D and 3D visuals. Participants from both groups offered insights into the strengths and weaknesses of each format. Advanced group participants often provided technical feedback, such as issues with blurring and artifacts in 3D models. They also discussed how the presentation context influenced their preference for 2D or 3D visuals. In contrast, the end-user group emphasized clarity and focus, particularly in contexts where these elements were crucial for understanding the content.

Both groups appreciated the immersive qualities of 3D visuals but had different focuses. The advanced group was more critical and detailed in their analysis, emphasizing the importance of technical refinement. Conversely, the end-user group focused on the overall visual impact and immersive experience of 3D visuals. This comparative analysis highlighted the diverse perspectives and preferences between the two groups, shaped by their varying levels of technical knowledge and viewing priorities.

4.3 Impact on viewer engagement

The theme of viewer engagement emerged prominently in the responses. Participants from both groups highlighted how 3D representations influenced their engagement with the content. The advanced group noted that 3D models enhanced the interactive and immersive experience, making the broadcast more engaging. They were intrigued by the novelty and substantial impact of 3D displays, considering them more convincing than traditional formats. Technical discussions included camera movement, depth, and integrating 3D models with the studio setting.

Similarly, the end-user group was impressed by the attention-grabbing features of 3D models, particularly their dynamic positions and layouts. They appreciated how 3D visuals effectively captured their attention and heightened engagement, especially with camera movement. Despite some technical imperfections, such as fuzzy edges and insufficient shadowing, participants acknowledged the enhanced realism and engagement provided by 3D representations.

4.4 Role of graphics and visuals in broadcasting

Participants also discussed the significant role of well-designed graphics and visuals in enhancing the viewing experience. Both groups acknowledged that high-quality graphics contribute substantially to the show's professionalism and perceived quality. The advanced group focused on these elements' professional and informational impact, recognizing their role in conveying information effectively and providing context. They debated the influence of graphics on viewing choices, with some seeing them as secondary to content and others considering them critical.

The end-user group emphasized graphics' immersive and informative qualities, noting how they capture attention and make the show more exciting. They valued the role of graphics in aiding content comprehension and simplifying complex information. Discussions also included the potential of interactive graphics and AR technology to enhance the viewer experience further, with the advanced group focusing on their functional aspects and the end-user group on their novelty and visual appeal.

4.5 Enhancing content with on-screen images and statistics

On-screen images and statistics were seen as beneficial augmentations to the viewing experience, particularly in sports broadcasting and data-centric discussions. Participants from both groups concurred that these elements enriched their understanding and engagement with the content. While not the primary motivator for watching a program, on-screen visuals enhanced the program's appeal and production value.

The advanced group noted that on-screen visuals made programs more visually engaging and dynamic, contributing to a deeper understanding of the content. They highlighted the role of these visuals in enhancing production values and overall aesthetic appeal. Similarly, the end-user group emphasized the role of well-executed on-screen images and stats in distilling complex information and adding an extra dimension of engagement. However, both groups agreed that personal interests and the core content of the show are the predominant factors influencing their decision to watch.

4.6 Applications of mixed reality in different TV show genres

Participants identified several TV show genres that could benefit from integrating mixed-reality video formats. Both groups suggested suitable genres for sports broadcasts, educational content, documentaries, news programs, and entertainment shows. They acknowledged the potential of mixed reality to amplify viewer engagement and comprehension across diverse content types.

Sports programs were seen as particularly well-suited for mixed reality applications, with participants highlighting sports commentary enhancement and the presentation of the statistics. Educational TV shows and documentaries were also mentioned, with mixed reality helping visualize complex topics and making them more accessible and engaging. Both groups recognized the potential of mixed reality in news and current affairs programming, which could aid in visualizing data and explaining concepts.

4.7 Enhanced production tools and their impact on broadcasting

The impact of enhanced production tools, especially 3D technology, on a show's production value was widely acknowledged. Participants noted that these tools intensify immersion, facilitate information conveyance, improve communication clarity, and create a more captivating and refined viewer experience. Both groups concurred that enhanced production tools could augment viewer immersion, offering a more lifelike and vibrant viewing experience.

The advanced group emphasized the significant contribution of 3D assets in creating a polished look and suggested a higher budget and skilled production team. They provided detailed examples of 3D applications in various contexts, such as sports broadcasting and medical education. Similarly, the end-user group believed such tools contribute to the show's professional appearance, enhancing viewer engagement and confidence. Both groups highlighted the role of these tools in enriching the viewer experience by providing detailed visual information and maintaining viewer interest.

4.8 Personal use of 3D assets and avatars

Finally, participants expressed interest in using 3D assets and avatars. Both groups acknowledged various potential benefits, including creative content creation, visualization, entertainment, education, personalization, and marketing. The advanced group provided a more extensive list of possible applications, while end-user participants focused on more personal and pragmatic uses.

Participants saw creative uses for 3D assets in video game design, 3D modeling, AR, graphic design, and animation. They also highlighted the potential for 3D assets in visualization, mainly through AR, to enhance experiences and provide interactive demonstrations. Both groups recognized the use of 3D assets in entertainment, including their integration into video games and XR applications.

Regarding personal 3D avatars, participants showed interest in enhancing virtual interactions, social media engagement, and entertainment experiences. The advanced group outlined various potential applications, spanning professional to emerging technological contexts. In contrast, end-user participants centered on more immediate personal uses for communication and engagement. While both groups shared enthusiasm for the potential of personal 3D avatars, their perspectives varied, with the advanced group exploring a broader range of uses and the end-user group focusing on practical applications.

4.9 Summary of results

Overall, the results reveal that both advanced and end-user groups appreciate the immersive and engaging qualities of 3D representations. The advanced group provided detailed technical feedback, while the end-user group focused on the overall visual impact. Both groups recognized the role of high-quality graphics and visuals in enhancing the viewing experience. They acknowledged the potential of MR and 3D technology to elevate production value and viewer engagement.

These findings align with our research objectives by highlighting the impact of 3D/volumetric content on viewer engagement and providing guidelines for content creation based on user preferences and profiles. The detailed insights from both groups offer valuable perspectives for broadcasters and content creators aiming to leverage 3D technology to enhance viewer experiences.

5 Discussion

In the findings of our study, we addressed several research questions relating to integrating XR technology into traditional broadcasting pipelines. Our findings illuminate advanced and end-user groups' nuanced perceptions and preferences, providing valuable insights into how XR technologies, mainly 3D content creation, influence production quality, viewer engagement, and the broadcasting landscape [8, 49, 80].

5.1 The impact of XR technology in broadcasting

Our investigation into integrating XR technology within traditional broadcasting pipelines uncovered significant production quality and viewer engagement improvements. This enhancement becomes significantly pronounced in real-time broadcasts, where XR technology's ability to introduce immersive and realistic 3D representations plays a pivotal role. As highlighted in the results section, both advanced and end-user groups noted the immersive quality and enhanced realism provided by 3D models. Participants frequently highlighted the depth and presence offered by these models, affirming XR technology's capacity to transform viewer perception and interaction with broadcast content. Despite some concerns regarding the fidelity and orientation of 3D models, these issues point to areas requiring further technological refinement [81]. The overall potential of XR technology remains high, emphasizing the need for ongoing advancements to fully harness its capabilities and enhance realism and viewer immersion in broadcasting, thereby shaping a more sophisticated and engaging broadcast landscape.

5.2 Benefits and limitations of 2D vs. 3D content creation

Our exploration of 2D and 3D content creation approaches in the context of XR broadcasting revealed distinct inherent advantages and challenges. While 2D visuals are broadly valued for their clarity and straightforward interpretability, making them practical for concise information conveyance [82], 3D content is lauded for its immersive and realistic properties. As detailed in the results in Sect. 4, both advanced and end-user groups recognized the merits of each format. The advanced group often provided technical feedback on 3D content, such as issues with blurring and artifacts. In contrast, the end-user group focused more on the overall visual impact and immersive experience of 3D visuals. The study underscores the complementary nature of these two modalities: 2D content is crucial for clear information delivery, while 3D content significantly enhances viewer engagement, making the broadcast more lifelike and captivating [83].

5.3 Advancements in AI and volumetric reconstruction

The study proposed to explore the burgeoning field of AI and volumetric reconstruction, particularly their roles in addressing the intricacies of incorporating live-action content into XR broadcasting environments. Our findings suggest that recent technological advancements hold substantial promise in overcoming some of the prevailing challenges in XR broadcasting. Participants acknowledged the significant potential of AI and volumetric reconstruction in enhancing the realism and interactivity of live-action content. As reflected in the Results section, these technologies are pivotal in improving the quality of 3D models, enhancing animation fluidity, and ensuring seamless integration of virtual elements into live broadcast environments [84]. However, the need for continued development was emphasized, particularly in enhancing the fidelity and integration of 3D models to create more lifelike and engaging XR experiences. This feedback underscores the dynamic interplay between technological capability and content quality, pointing to a future where AI and volumetric reconstruction could revolutionize how live-action content is presented and experienced in XR broadcasting.

5.4 Efficiency and cost-effectiveness in remote production

Incorporating XR technologies into broadcasting has notably impacted production workflows, with a marked influence in remote production environments. As noted in the Results, participants pointed out that XR technologies significantly streamline production processes, enhancing efficiency and cost-effectiveness, particularly in scenarios demanding quick content turnaround and high adaptability [80]. This streamlining effect is especially pertinent in the modern broadcasting landscape, where agile and responsive production methods are paramount. The observations suggest that XR technologies facilitate smoother and more flexible production workflows, presenting opportunities for cost savings, especially in remote setups where traditional production methods may be logistically challenging or financially prohibitive.

5.5 Implications for multi-platform content distribution

The integration of XR and AI within the broadcasting sector profoundly impacts content distribution across multiple platforms, as highlighted by our study's participants. They recognized that these advanced technologies significantly augment interactivity and enrich the viewer experience. This enhancement is particularly relevant in today's diverse media landscape, where content is consumed across various platforms, from traditional broadcasting channels to online streaming services and social media platforms [85]. The implications of volumetric reconstruction for broadcasting and interactive media are profound. As detailed in the Results, for broadcasters, volumetric processes offer new storytelling tools, allowing audiences to experience events and narratives more engaging and immersively. Whether giving viewers a 360-degree view of a live sports event or creating interactive news stories, volumetrics expands the possibilities of audience engagement.

Our findings indicate that incorporating XR and AI not only elevates the quality of content but also broadens its appeal, making it more engaging and accessible to a broader audience. This is especially critical in an era of rapidly shifting consumer preferences and the growing demand for personalized and interactive media experiences. The study suggests that XR and AI lead to more adaptable content resonating with evolving media consumption patterns, enabling broadcasters to reach and engage audiences across various digital platforms effectively. Integrating XR and AI technologies in broadcasting represents a significant step towards more dynamic and immersive multi-platform content distribution. It promises to transform how content is created, delivered, and experienced, aligning with contemporary media consumption trends and audience expectations.

6 Guidelines

Our research highlights the transformative impact of XR technology in the broadcasting sector. From enhancing real-time broadcasts with immersive 3D visuals to improving content production and distribution efficiency, XR technologies are reshaping media creation and consumption. The insights from both advanced and end-user groups provide a comprehensive understanding of XR's current state and future potential in broadcasting, pointing towards a more interactive, engaging, and versatile media landscape. The following guidelines can be drawn from the presented findings:

1. **Diverse Preference Considerations:** The study highlights the importance of recognizing and accommodating various preferences when incorporating visual elements, such as 2D and 3D graphics. Acknowledging the varying tastes of viewers and content creators is essential for creating a more engaging and immersive visual experience.
2. **Quality and Realism Matter:** The quality and realism of visual elements, particularly in 3D graphics, are critical factors in enhancing viewer engagement and satisfaction. Attention to detail, fidelity, and overall visual appeal create a more authentic and captivating experience.
3. **Balance Between Modalities:** While 2D and 3D visuals have merits, balancing them can enhance content creation and viewing experience. Integrating the strengths of each modality while addressing their limitations can result in a more well-rounded visual presentation.
4. **Interaction and Responsiveness:** The study emphasizes the importance of interaction and responsiveness in 3D graphics. Dynamic camera movements, occlusions, and changes in perspective associated with 3D models can significantly enhance viewer immersion and engagement compared to static 2D visuals.
5. **Enhancing Production Value:** Incorporating additional visual intricacies, such as reflections, shadows, and lighting effects, can augment the production value of 3D models. These elements contribute to a more visually appealing and captivating experience, providing a competitive edge in content creation.

6. **Context-Dependent Design:** The effectiveness of visual elements, whether 2D or 3D, is context-dependent. Understanding the genre, nature of the program, and specific content creation goals is crucial in determining the appropriate use of visual aids to enhance engagement and convey information effectively.
7. **Viewer Engagement through Graphics:** On-screen graphics and statistical representations significantly enhance viewer engagement. When aligned with quality content, well-executed graphics capture attention, provide valuable information, and create an enjoyable viewing experience.
8. **Practical Application and Innovation:** The study underscores the practical applications and innovative potential of 3D assets beyond entertainment, including education, art, marketing, and personalized expression. Leveraging these assets can lead to diverse and engaging creative content across various domains.
9. **Technical Expertise and Resource Allocation:** Effectively utilizing 3D tools requires technical expertise and prudent resource allocation. Balancing cost-effectiveness and quality ensures the optimal implementation of 3D graphics and assets to achieve the desired impact.
10. **Privacy and Authenticity Considerations:** When incorporating personal avatars and immersive experiences, concerns regarding privacy and authenticity should be addressed. Ensuring that users' privacy is respected and that the avatars align with genuine representations contributes to a positive and trustworthy user experience.

These guidelines emphasize the importance of understanding content creator preferences, enhancing visual quality and realism, balancing different modalities, and creatively leveraging visual elements to improve engagement and convey information effectively in various content creation contexts.

7 Limitations and future work

While the chosen methodology offers valuable insights into user attitudes toward real-time content creation for live studio broadcasts, it's essential to be aware of the limitations that could impact the generalizability and depth of the findings. The study relies on voluntary participation, which can lead to volunteer bias. Participants who choose to participate might have different attitudes or motivations than those who do not participate, potentially affecting the generalizability of the findings. The recruitment of participants through internal and external media networks and social media could result in sampling bias. The participants may not represent the broader population accurately, mainly if certain groups are overrepresented or underrepresented. Removing novice users from the study may limit understanding of potential challenges or benefits for this user group. Their perspectives could offer valuable insights into the usability and accessibility of the technology.

Future research could adopt a comprehensive approach to address these limitations—this might involve implementing a mixed-methods sequential design with both quantitative surveys and qualitative interviews to capture a holistic view of user attitudes. Employing a random sampling technique and including diverse user groups, such as novices and professionals, would enhance the study's representativeness. Longitudinal research spanning a significant timeframe could assess both immediate impressions and long-term effects.

8 Conclusions

In this paper, we explored the transformative potential of volumetric technology in reshaping the landscape of broadcasting, metaverse production, and real-time 3D asset creation. By integrating humancentric volumetric reconstruction and 3D render engines, we proposed a forward-looking framework for the live studio of the future, aiming to enhance content creation and delivery across diverse platforms such as traditional broadcast, live streaming, the metaverse, and interactive channels. We examined the technical advancements, workflow integration, potential challenges, and future implications of volumetric reconstruction in media production.

XR technology finds applications across various fields, including entertainment, gaming, education, training, design, architecture, healthcare, and more. It offers opportunities for enhanced visualization, interactive storytelling, immersive training simulations, collaborative design, and engaging user experiences. As XR technology advances, we can expect further improvements in hardware capabilities, tracking accuracy, display qualities, and the range of interactive experiences it can offer. While mixed reality in broadcasting is still in its early stages, it holds immense potential to transform how content is created, delivered, and experienced. As XR technology advances, we expect to see more innovative applications and integration of mixed realities into modern broadcast systems.

Creating multi-platform content for distribution, including traditional broadcast channels, streaming services, social media platforms, and dedicated apps, allows broadcasters to reach a wider audience and provide content creation for various devices. This multi-platform approach has been shown here to enhance viewer engagement across multiple dimensions and user types. Thus, many opportunities exist for modern broadcast systems to be further enhanced by XR technology. First, XR technology has the potential to significantly improve viewer experiences and introduce new interactive elements in modern broadcast systems. Secondly, by seamlessly integrating virtual objects into the user's physical environment, XR can improve visualizations, revolutionize set design, facilitate remote production, and provide innovative advertising and sponsorship integration opportunities.

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Data availability The data supporting this study's findings are not openly available due to reasons of anonymity but are available from the corresponding author upon reasonable request.

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