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Systematic Literature Review of 3D Object Replacement Algorithms in Live Broadcasts

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Abstract. The exponential growth of live broadcasts has exacerbated the exposure of vulnerable audiences to inappropriate visual content, surpassing the capabilities of traditional reactive moderation. This systematic literature review investigates the potential of 3D object replacement algorithms as a proactive real-time solution. By analyzing research from the last five years, the study identifies key methodologies in photogrammetry, deep learning, and physically based rendering capable of dynamic substitution. Results indicate that while detection and modeling technologies are advanced, significant challenges regarding latency and visual coherence in dynamic environments remain. The paper concludes that integrating these technologies offers a promising pathway for automating content safety, particularly for protecting minors, though further research on real-time optimization is required.
Keywords: 3D Object Replacement, Live Streaming, Content Moderation, Computer Vision, Photogrammetry.

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1 Introduction

The digital landscape has been radically reshaped by the dominance of live Broadcasts, a format that enables real-time audiovisual delivery across global platforms without the latency of prior recording (Mantri, 2021; Zhang et al., 2018). While immediacy fosters authentic interaction, it simultaneously introduces severe risks regarding the uncontrolled dissemination of offensive material, ranging from weapons and drug paraphernalia to explicit violence, which cannot be effectively filtered by traditional, reactive moderation (Ferrara et al., 2021). This structural inability to vet content before transmission exposes vulnerable audiences, particularly minors, to harmful imagery before protective measures can be deployed, creating a critical safety gap in the modern digital ecosystem (Cai & Wohn, 2019; Zhang et al., 2018).

The technical architecture of live broadcasts, characterized by bidirectional transmission without prior storage, renders standard pre-broadcast censorship obsolete (Van Holland et al., 2023; Yu et al., 2025). Within these ephemeral environments, inappropriate elements are often dynamic components of the scene rather than static overlays (Gómez Echeverry et al., 2018; Martínez et al., 2009). In this context, 3D objects, defined as digital three-dimensional representations functioning as avatars or interactive assets, emerge as pivotal elements (Deng et al., 2023; Meng et al., 2025; Van Holland et al., 2023). Understanding the manipulation of these spatial entities is essential, as their intrinsic properties offer a novel pathway for addressing visual safety challenges that 2D text-based filtering cannot resolve (Alcántara et al., 2024).

Emerging as a sophisticated strategy for real-time content management, 3D object replacement algorithms provide a proactive alternative to simple detection (Mori et al., 2017). These computational techniques identify specific three-dimensional entities within a digital scene and dynamically substitute them with benign alternatives (Meerits & Saito, 2015; Sui et al., 2022). By leveraging advancements in photogrammetry and physics-based rendering (PBR), these systems ensure that substitutions integrate harmoniously with the environment's lighting and geometry (Kakkar et al., 2024). The objective is a seamless visual alteration that sanitizes the broadcast signal instantly, preventing exposure rather than merely flagging the violation after it has occurred (Herling, 2014). These techniques extend a long line of geometric foundations, from early 3D object reconstruction from calibrated images (Grandón-Pastén et al., 2007) and automated digital photogrammetry (Rodríguez Navarro, 2012) to the generation of video from 3D models (Galcerá et al., 2009).

Despite significant strides in 3D reconstruction, Augmented Reality (AR), and Digital Twin technologies, a notable disconnect remains in the literature (Ingale & J., 2021; Kamali et al., 2024; Luque Ordóñez, 2020; Sánchez García et al., 2022). While the capability to capture and render realistic 3D models is well-established across entertainment, industry, and education (Pardo-Gómez et al., 2023; Roa Becerra et al., 2022), research applying these mechanisms specifically to the automated censorship of live broadcasts is scarce (Xiao, 2023). Current academic efforts predominantly focus on text analysis or static 2D image recognition, leaving the complex, dynamic threat of volumetric visual elements largely unaddressed (Gongane et al., 2022; Xiao, 2023). Addressing this technological disparity constitutes the primary focus of this systematic review. By analyzing the current state of scientific literature, this study aims to validate the viability of 3D object replacement as a standard filtration protocol. The review critically evaluates existing methodologies and technical limitations, such as latency and visual coherence, to determine how these algorithms can be deployed to bridge the gap between advanced computer vision capabilities and practical, real-time online safety policies.

2. Experimental procedures

This research employed a Systematic Literature Review (SLR), a rigorous and transparent methodological approach designed to identify, evaluate, select, and critically synthesize all available pertinent research on a specific topic (Kitchenham et al., 2007). This methodology is optimal for mapping existing knowledge, defining the "state of the art" in the field, and identifying gaps requiring further investigation. The review process is organized into the following key phases, adhering to the recommendations of the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) and other accepted methodologies for SLRs in engineering and computer science.

2.1 Formulation of Research Questions: The systematic review is guided by the following central question: What algorithms enable 3D object replacement, and how can they be applied to moderate inappropriate content in live broadcasts over the last 5 years? To support the main review, the following sub-questions (SQ) guide the search and analysis: **SQ1:** What techniques or algorithms have been recently developed to detect and replace 3D objects in virtual environments or video broadcasts? **SQ2:** Are there recent applications or studies directly connecting 3D object replacement algorithms with content moderation or filtering in live broadcasts? **SQ3:** What are the primary technical challenges and limitations observed in the real-time implementation of these algorithms, such as latency, occlusion, or visual consistency? **SQ4:** What ethical issues or privacy considerations arise from using these technologies for content moderation?

2.2 Inclusion and Exclusion Criteria
To ensure the relevance and quality of the selected studies, the following criteria are applied. Inclusion Criteria: *Publication Date* Articles available at the time of the search (up to May 24, 2025), with no lower date restriction. Articles bearing a 2026 publication year were included when confirmed to be available online prior to the search closure date, as several journals release papers digitally ahead of their print issue date. *Publication Type***.** Academic articles (peer-reviewed journals, conferences), systematic reviews, book chapters, and these present original research or detailed analyses. *Language*. Publications principally in Spanish or English. *Content Relevance*. Studies addressing the development or application of algorithms for 3D object replacement, detection, or manipulation; Research on content moderation in live broadcasts or real-time video platforms; Studies analyzing the intersection of 3D technologies such modeling, AR, computer vision with online safety or content filtering; Articles addressing technical difficulties or performance aspects in real-time systems linked to 3D graphics or video processing. Exclusion Criteria: ; Opinion pieces, editorials, news, blogs, or non-academic writings; Articles without full-text access; Research not involving 3D objects or manipulation algorithms, e.g., studies focused solely on text or 2D images without depth; Studies on 3D modeling or AR/VR lacking a clear connection to visual content manipulation, modification, or moderation.

2.3 Search Strategy
The search is conducted in academic databases and scientific literature repositories recognized for their focus on engineering, computer science, and communication. The selected databases include but are not limited to: Scopus; IEEE Xplore; and Redalyc (for Spanish publications relevant to the Latin American context). The exact search strings executed within the search window (up to 24 May 2025) were as follows. Scopus: TITLE-ABS-KEY (("3D object" OR "3D model" OR "3D reconstruction" OR "three-dimensional reconstruction" OR "point cloud" OR "3D scene") AND (replacement OR substitution OR "diminished reality") AND ("real-time" OR live OR video OR streaming OR broadcast)) AND PUBYEAR > 2019 AND PUBYEAR < 2026 AND (LIMIT-TO (LANGUAGE , "English") OR LIMIT-TO (LANGUAGE , "Spanish")). IEEE Xplore (filters applied: Journals; years 2020-2025): ("All Metadata":"3D object" OR "3D reconstruction" OR "3D model") AND ("All Metadata":replacement OR substitution OR "diminished reality") AND ("All Metadata":"real-time" OR "live streaming" OR broadcast OR video). Redalyc (Spanish and English, given the repository's Latin American focus; years 2020-2025): ("objeto 3D"

OR "reconstrucción 3D" OR "modelo 3D") AND ("reemplazo" OR "sustitución" OR "realidad disminuida") AND ("tiempo real" OR "transmisión en vivo").

2.4 Study Selection

The selection of studies follows a two-stage process: *Stage 1: Title and Abstract Screening*. Independent reviewers analyze the titles and abstracts of all search results to identify potentially relevant studies. Reasons for excluding any study are documented. *Stage 2: Full-Text Review*. Studies selected in Stage 1 were retrieved in full. Independent reviewers examined the full texts, applying the inclusion and exclusion criteria in detail. Any discrepancies between reviewers were resolved through discussion and consensus, or, if necessary, via arbitration by an external reviewer. A Table 1 was generated to record the selection process, detailing the number of articles identified, screened, eligible, and included in the final review. The complete identification, screening, eligibility, and inclusion process is summarized in the PRISMA flow diagram (Figure 1).

Table 1. Article selection process

Stage	Scopus	IEEE Xplore	Redalyc	Total
Records identified	78	34	54	166
Full-text assessed (after screening)	8	4	4	16
Duplicate records removed	—	—	—	2
Studies included	—	—	—	**14**

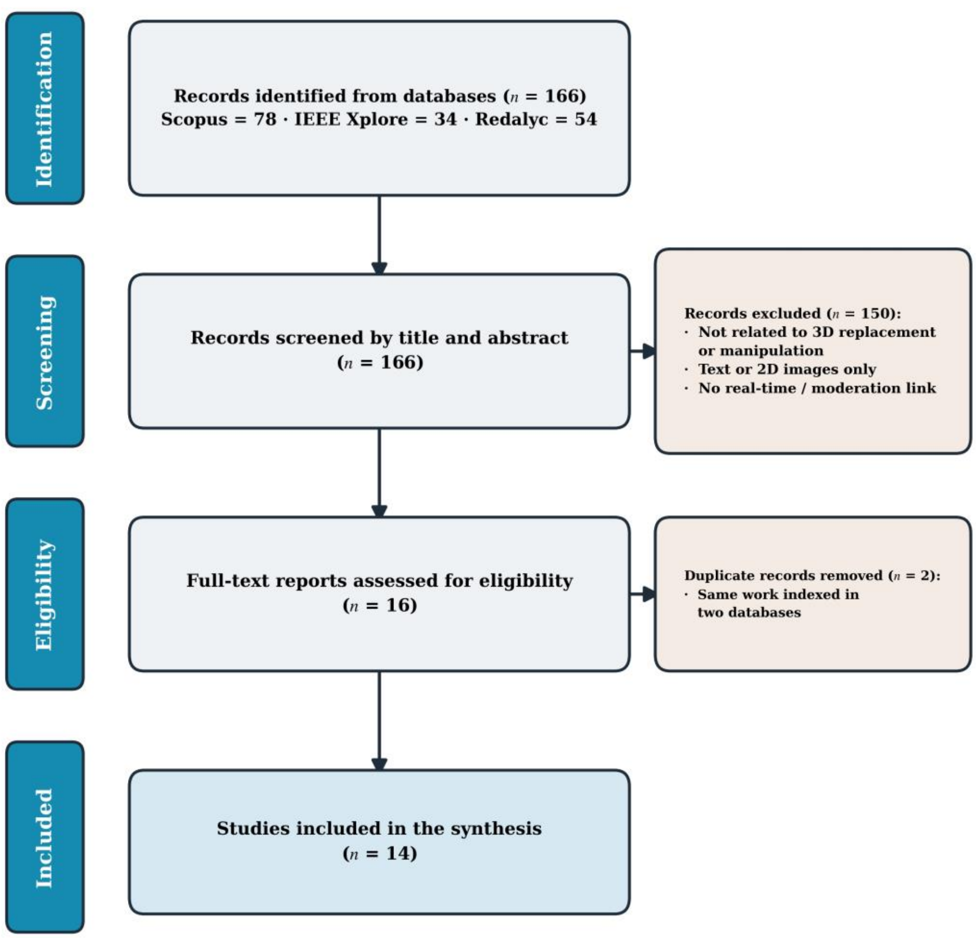

Figure 1. PRISMA 2020 flow diagram of the study selection process.

2.5 Data Extraction

For each included study, a standardized data extraction form was implemented to systematically collect relevant information. The extracted data covers: *General Information*. Title, authors, publication year, publication type, source. *Research Context***.** Application area (e.g., video games, AR/VR, security, moderation). *Methodology*. Study design, data types used, tools, or software. *Algorithm/Technique Description*. Name of the algorithm, operating principle, involved 3D objects (e.g., detection, replacement, manipulation). *Key Results*. Efficacy, performance, accuracy, latency, computational resources. *Challenges and Limitations*. Problems encountered during implementation or application. *Conclusions and Future Directions*. Study contributions and areas for future research. *Relevance to Live broadcasts Moderation*. Analysis of how results can be utilized for real-time inappropriate content moderation.

2.6 Information Synthesis and Analysis

Following data extraction, a narrative and thematic synthesis of the results is conducted. A numerical meta-analysis is not performed due to the expected variability among studies. Instead, the analysis focuses on: *Trend Detection*. Evaluating recent advances in 3D object replacement technology and its application across various fields. *Strategy Analysis*. Explaining the most common methods and approaches for modeling, detecting, and substituting three-dimensional objects. *Convergence Investigation*. Examining how and to what extent these algorithms have been or can be implemented for content moderation during live broadcasts. *Challenge Evaluation*. Summarizing technical difficulties (performance, response time, visual coherence, stability) and non-technical issues (ethics, privacy) related to adopting these solutions in real-time. *Knowledge Gap Identification*. Recognizing areas where research is limited or absent, highlighting opportunities for future studies.

2.7 Quality Assessment of Included Studies

Following the approach of Kitchenham et al. (2007), each included study was appraised against six quality criteria, scored 0 (no), 0.5 (partial), or 1 (yes). Three criteria assess methodological rigour: (QA1) clarity of objectives or research questions; (QA2) replicability of the described method; and (QA3) empirical validation of results. Three criteria assess relevance and technical contribution: (QA4) direct contribution to 3D reconstruction, replacement, or manipulation; (QA5) treatment of real-time constraints (latency, occlusion, robustness); and (QA6) connection to content moderation or visual safety. The per-study scores (Table 2) weigh the evidence in the synthesis rather than serving as an additional exclusion filter.

Table 2. Quality assessment scores of the 14 included studies

Study	QA1	QA2	QA3	QA4	QA5	QA6	Total	Quality
Chen et al. (2026)	1	1	1	1	0.5	0	4.5	Medium
Fabra et al. (2024)	1	0.5	0.5	1	0.5	0	3.5	Medium
Petrovska & Jutzi (2024)	1	1	1	1	1	0	5.0	High
Rangelov et al. (2024)	1	1	1	1	0.5	0	4.5	Medium
Korycki et al. (2025)	1	1	1	1	0.5	0	4.5	Medium
Pepe et al. (2023)	1	1	1	1	0.5	0	4.5	Medium
Muñoz et al. (2024)	1	0.5	0.5	1	0	0	3.0	Medium
Helle & Lemu (2021)	1	1	1	1	0	0	4.0	Medium
Sui et al. (2022)	1	1	1	1	1	0	5.0	High
Benítez Obando et al. (2024)	0.5	0.5	0	0.5	0	0	1.5	Low
Deng et al. (2023)	1	1	1	1	1	0	5.0	High
Van Holland et al. (2023)	1	1	1	1	1	0.5	5.5	High
Yu et al. (2025)	1	1	1	0.5	1	0	4.5	Medium
Olmedo López & Torrico Irahola (2023)	0.5	0.5	0.5	0.5	1	0.5	3.5	Medium

2.8 Ethical Considerations and Tool Management

Since this is a literature review, direct human subject participation is not involved. However, strict adherence to copyright laws is ensured by correctly citing all consulted sources and avoiding plagiarism. Emphasis is placed on discussing the ethical and privacy implications of the technologies studied, particularly regarding content moderation and the protection of vulnerable groups. To facilitate this process, reference management software Mendeley was employed to efficiently classify and manage retrieved articles and their metadata, ensuring accurate citation and referencing throughout the study.

3 Results

The systematic search yielded 14 studies that met the inclusion criteria. Rather than presenting these studies individually, this section synthesises their evidence across three analytical axes derived from the research sub-questions: (i) the families of 3D reconstruction and modelling methods reported (SQ1); (ii) their demonstrated capability under real-time constraints (SQ3); and (iii) the extent to which the literature connects these techniques to content moderation in live broadcasts (SQ2, SQ4). Each study was appraised with a six-item quality assessment (Section 2.8); the synthesis below weights the evidence, accordingly, foregrounding higher-quality studies and treating lower-quality ones as supporting context.

3.1 Methods for 3D reconstruction and modelling

Neural Radiance Fields (NeRF) constitute the dominant and most active line of work, accounting for six of the fourteen included studies. Across these studies, NeRF is consistently reported to outperform traditional mesh-based pipelines in photorealism and in reconstructing complex optical effects from sparse views. The contributions are, however, complementary rather than redundant: Chen et al. (2026) address the spatial incoherence of tensor-based NeRF to recover fine-grained geometry; Petrovska and Jutzi (2024) demonstrate NeRF's capacity to recover occluded geometry through obstacles, reporting up to 93% point coverage where Multi-View Stereo fails; Rangelov et al. (2024) quantify how acquisition parameters (ISO, shutter, aperture) condition reconstruction quality; Korycki et al. (2025) and Pepe et al. (2023) benchmark NeRF and Instant-NGP against established photogrammetric software, confirming competitive results under weak image geometry while noting residual limitations in metric accuracy. Taken together, the NeRF evidence is methodologically robust (four of these studies scored 4.5 or higher out of 6) but is concentrated in static-capture domains.

Photogrammetry and structured-light reconstruction form a second, more mature family. Helle and Lemu (2021) validate 3D scanning for reverse engineering and quality control, and Muñoz et al. (2024) demonstrate object cloning through fringe projection coupled with 3D printing. These methods achieve high metric fidelity but are demonstrated only on controlled, static objects, limiting their direct transfer to live scenes.

Dynamic and temporal reconstruction is the family most relevant to substitution in motion, yet the least populated. Sui et al. (2022) achieve accurate reconstruction of dynamic objects via spatial-temporal multiplexing with explicit motion-induced error elimination, and Deng et al. (2023) demonstrate real-time interaction with 3D human representations in virtual environments. Both scored 5.0 out of 6 and represent the corpus's strongest evidence that moving 3D entities can be reconstructed and manipulated in near real time.

Applied and visualisation-oriented modelling comprises the remaining studies, which apply 3D assets to specific domains—digital twins for real-time workshop monitoring (Yu et al., 2025), augmented-reality integration in television production (Olmedo López & Torrico Irahola, 2023), live-telepresence streaming (Van Holland et al., 2023), 3D representation in the industrial metaverse (Fabra et al., 2024), and 3D modelling for digital advertising (Benítez Obando et al., 2024). These studies contribute less to reconstruction methodology but more to deployment context, and are discussed further in Section 3.2.

3.2 Capability under real-time constraints

Mapping the corpus against the technical demands of live broadcasts—low latency, occlusion handling, and robustness to a changing scene—exposes an uneven evidence base.

Occlusion handling is the single constraint with strong, direct evidence: Petrovska and Jutzi (2024) explicitly target reconstruction behind obstacles, a capability essential for substituting partially covered objects. Dynamic-scene robustness is supported by Sui et al. (2022) and Deng et al. (2023), the only studies that demonstrate reconstruction or interaction with moving targets at interactive rates. Streaming and multi-client delivery is addressed solely by Van Holland et al. (2023), whose live-telepresence system is the closest analogue in the corpus to a broadcast pipeline. Latency itself is treated only indirectly: speed-oriented advances such as Instant-NGP's hash-encoding (Pepe et al., 2023) and the efficiency gains reported by Chen et al. (2026) suggest feasibility, but no included study measures end-to-end latency for a full detect–reconstruct–substitute–render loop. By contrast, the photogrammetry and structured-light studies (Helle & Lemu, 2021; Muñoz et al., 2024) provide no real-time evidence. The synthesis therefore indicates that the technical building blocks for real-time 3D substitution exist but remain fragmented across separate studies: no single work demonstrates the integrated pipeline that live moderation would require.

3.3 The moderation gap: a convergence not yet realized

The most consequential finding of this review is an absence. Of the fourteen included studies, none addresses the application of 3D object replacement to content moderation, and only two (Van Holland et al., 2023; Olmedo López & Torrico Irahola, 2023) operate in a broadcast-adjacent context at all. The ethical and privacy dimensions raised in SQ4 are likewise almost entirely absent from the technical corpus. This pattern is not incidental: it reflects a genuine disconnect between a technically advanced field (3D reconstruction and neural rendering) and an application domain (real-time visual moderation) that has not yet adopted it.

Accordingly, the convergence between 3D object replacement and live-broadcast moderation should be read not as an established result but as the research gap that this review documents. The capability to detect, reconstruct, and re-render 3D content is demonstrably maturing; its deployment as a proactive moderation mechanism remains, to date, unexplored in the peer-reviewed literature.

Table 3. Summarizes the method families, representative studies, reported strengths, and limitations.

Method family	Representative studies	Reported strengths	Key limitations	Real-time evidence
Neural Radiance Fields (NeRF)	Chen (2026); Petrovska & Jutzi (2024); Rangelov (2024); Korycki (2025); Pepe (2023); Fabra (2024)	Photorealism from sparse views; occlusion recovery; fast variants (Instant-NGP)	Concentrated in static capture; residual metric-accuracy gaps	Partial
Photogrammetry / structured light	Helle & Lemu (2021); Muñoz (2024)	High metric fidelity; mature tooling	Controlled, static objects only	None
Dynamic / temporal reconstruction	Sui (2022); Deng (2023)	Moving-object reconstruction; interactive rates	Few studies; constrained settings	Strong
Applied / visualisation	Van Holland (2023); Yu (2025); Olmedo López & Torrico Irahola (2023)	Deployment context (streaming, AR-TV, digital twins)	Limited reconstruction-method novelty	Mixed

3.4 Recommendations for future research

Based on the findings of this comprehensive study regarding the state of 3D object replacement algorithms and their potential application in live content moderation, the following general suggestions were proposed for future research and technological advancement:

Fostering Specialized Research in 3D Replacement for Moderation

Focus on Combined Algorithms. Existing literature shown progress in detection/reconstruction (Muñoz et al., 2023; Kovac et al., 2021) and real-time rendering (Luis Tello, 2023). The study suggested researching and developing combined algorithms that integrated these functions. Such algorithms were expected to be capable of: Identifying and categorizing objects in real-time (leveraging deep learning in computer vision); Agilely recreating or deducing the 3D shape of the identified object; Substituting it with an alternative 3D model (predefined or dynamically generated); Rendering the modified scene with adequate visual coherence (lighting/occlusion) and minimal response time.
Creation of Adaptive Replacement Models. The study recommended investigating the development of 3D replacement model banks that could dynamically adjust to the broadcast environment (lighting, camera angle, movement). This implied employing advanced real-time rendering techniques and potentially deep learning to achieve coherent textures and materials.

Addressing Technical Challenges with Specific Strategies

Optimization for Latency Reduction. The review determined that future research needed to aim to improve algorithms to significantly decrease latency. This included: Designing parallel or distributed processing structures; More efficient use of specific hardware (e.g., GPUs and TPUs); Implementing motion-prediction algorithms to anticipate scene changes and shorten response time; Developing "data fusion" methods integrating various sources (video, depth sensors) to improve detection and tracking.

Strengthening Robustness Against Occlusions and Environmental Changes. To address significant challenges posed by occlusions and environmental variations, the study **recommended** investigating: Reconstruction and tracking algorithms effective against partial or complete occlusions; Real-time lighting estimation techniques to adapt the replacement model to broadcast light conditions; Incorporating deep learning to adjust the replacement 3D model to complex backgrounds and changing textures.

Optimizing the Use of Deep Learning

Detection and Classification of Inappropriate Content. Continued exploration of deep learning was deemed fundamental for precise, real-time identification of inappropriate objects and actions. This encompassed not only static object detection but also the identification of problematic moving actions or contexts.
Conditional Generation of 3D Models. The review suggested investigating the use of generative networks (such as GANs) for the automatic creation of alternative 3D models that fitted the peculiarities of the original object or environment, offering a more flexible solution than static libraries.
Improving Photorealism and Visual Coherence. The study emphasized deepening the understanding of how deep learning could bridge the gap between real and generated content using style transfer, texture creation, and material simulation.

3.4 Ethical and Social Aspects

Ethical and Privacy Framework. The analysis **concluded** that technological advancement **needed** to be accompanied by a thorough examination of ethical and privacy implications. Guidelines **were suggested** to consider transparency regarding real-time modification, protection of freedom of expression (preventing excessive censorship), appeal processes for content creators, and informed consent.
Focus on Minor Protection. The review **prioritized** the development of technologies specifically aimed at protecting vulnerable populations, such as minors, where replacing inappropriate content **was** ethically defensible and socially imperative.
Interdisciplinary Collaboration. The study **encouraged** fostering cooperation between specialists in computer vision, 3D graphics, artificial intelligence, ethics, sociology, and interface design to create solutions that **were** technologically viable, ethically consistent, and socially acceptable.

4 Conclusions

This systematic review set out to determine whether 3D object replacement algorithms can serve as a proactive mechanism for moderating inappropriate content in live broadcasts. The evidence gathered from fourteen studies supports a more qualified conclusion than the field's enthusiasm might suggest. On one hand, the technical foundations are advancing rapidly: neural rendering—particularly NeRF and its accelerated variants—together with photogrammetry and dynamic reconstruction, now enables high-fidelity 3D capture, recovery of occluded geometry, and, in a minority of studies, interactive-rate manipulation of moving objects. On the other hand, no study in the corpus applies these capabilities to content moderation, and only two operate in a broadcast-adjacent setting. The convergence of 3D object replacement and live-broadcast moderation is therefore best characterised not as a demonstrated solution but as an open research gap that this review makes explicit.

Two obstacles stand out. The first is end-to-end latency across an integrated detect–reconstruct–substitute–render pipeline, which none of the included studies evaluates. The second is the preservation of visual coherence—consistent lighting, occlusion, and motion—under the uncontrolled conditions of a live scene. Until these are addressed in research that explicitly targets moderation, claims about 3D replacement as a deployable safety mechanism remain premature.

The contribution of this review is thus twofold: it maps a fragmented but promising technical landscape, and it identifies the disconnect between that landscape and the moderation application it could serve. Future work should pursue integrated pipelines evaluated under real-time constraints, accompanied by the ethical and privacy safeguards that real-time modification of broadcast content demands—with particular attention to protecting vulnerable audiences, for whom the case for intervention is strongest.

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