Storyboarding in Extended Reality: leveraging real-world elements in storyboard creation

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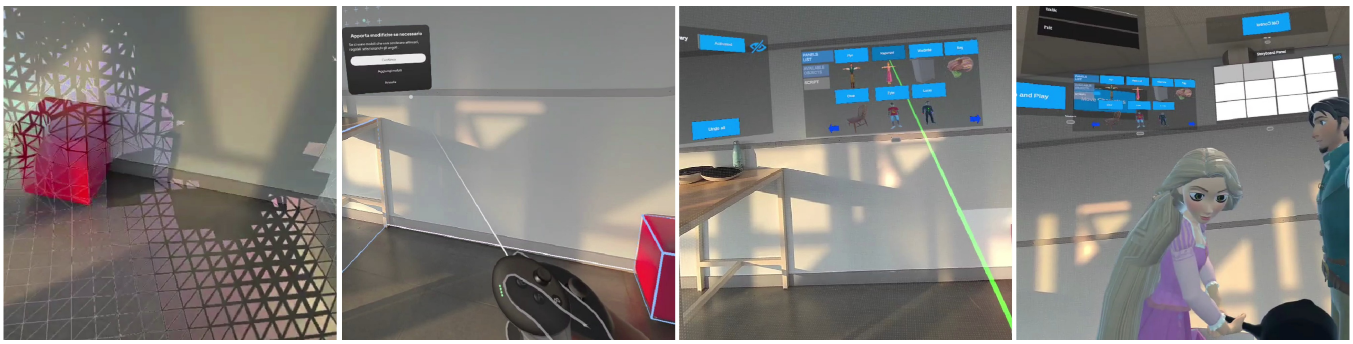

Figure 1: A novel storyboarding approach based on scanning the physical environment to define virtual bonds and objects of interest, setting up the virtual stage with real-scale 3D assets and characters, posing characters with a scene-enacting approach, and framing the scene from the user's point of view to create storyboard panels.

Abstract

Recent technological innovations, especially in extended reality (XR) and artificial intelligence (AI), redefine storytelling approaches. These innovations are expanding creative possibilities for filmmakers while transforming how audiences engage with and experience films and other entertainment products. Despite technological advancements, the pre-production phase depends primarily on traditional planning and visualization methods. This research proposes a novel paradigm to create storyboards in XR, leveraging the capabilities of object-detection and pose-estimation systems to benefit the storyboarding phase. An application has been designed and developed to create 3D storyboards on a real scale within a physical environment and all its furniture. Wearing a head-mounted display for XR, users can move in the physical space, enrich it with virtual elements and characters, and frame the environment to obtain storyboard panels that mix real and virtual elements. The proposed system has been tested to assess its usability, and initial findings indicate that users have appreciated this application.

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CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; **Interactive systems and tools**; • **Computing methodologies → Mixed / augmented reality**; **Animation**; • **Applied computing → Media arts**.

Keywords

Storyboard, Extended Reality, Computer Animation, Authoring Tools

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1 Introduction

Cinema has always been a powerful medium for creativity, storytelling, and artistic expression. Over the past century, the film industry has continuously evolved, adapting to technological advancements and shifting audience expectations. The digital age, coupled with recent advances in immersive technologies and artificial intelligence (AI), is pushing the boundaries of cinematic storytelling, opening up new creative possibilities for filmmakers and screenwriters, thus changing how spectators interact with and watch movies. These advancements, from production techniques and visual effects to distribution models and audience engagement, redefine how films are conceived, created, and experienced [Kao and Kao 2023][Hutson 2023]. The production phase of cinematic and computer-generated imagery (CGI) sequences typically incorporates cutting-edge technologies, including advanced rendering engines, motion capture, and real-time virtual production techniques [Song et al. 2023][Nila et al. 2022]. These innovations enable filmmakers and animators to create highly detailed and visually stunning scenes with precise control over camera positions, lighting, textures, and character movements.

However, despite these technological advancements in production, the pre-production phase still heavily relies on more traditional methods of planning and visualization. Once the script is finalized, storyboard artists play a crucial role in translating written descriptions into visual blueprints for the movie production. They create 2D storyboard panels for each shot, meticulously sketching the background, foreground elements, and characters' actions to outline key moments in the narrative. These hand-drawn or digitally illustrated panels are a foundation for subsequent stages, helping directors, cinematographers, and animators establish composition, camera angles, and scene continuity before moving to full-scale production. Advances in information technology provided sketch-based and picture-based 2D drawing applications, as an alternative to traditional hand-drawn storyboards or physical mockups [Clever Prototypes, LLC 2025][Canva 2025]. Commercial applications for 3D pre-visualization (pre-vis), such as Frameforge 3D [Innoventive Software 2025] or Shot-Pro [WebGames3D.com 2023], have been proposed too. However, these approaches are time-consuming, as they may present a steep learning curve, and are usually complex to master, favoring skilled users. While digital tools and 3D pre-visualization techniques are increasingly integrated into production workflows, traditional storyboarding remains an essential and widely used practice in filmmaking and animation.

This research explores using extended reality and scene understanding capabilities based on AI models to benefit the storyboarding phase of movie production. An application has been designed and developed to create 3D storyboards on a real scale within a physical environment and all its furniture. Wearing a head-mounted display for XR, users can move in the physical space, enrich it with virtual elements and characters, and frame the environment to obtain storyboard panels that mix real and virtual elements. The proposed system has been tested to assess its usability, and initial findings indicate that users have appreciated the application.

The remainder of this article is organized as follows. Section 2 provides an overview of previous related works. Then, in Section 3, the design and development of the proposed system are described. Section 4 presents and discusses the preliminary experimental results. In Section 5, conclusions and future works are presented.

2 Previous Works

Recent scientific research highlights the increasing role of extended reality (XR) in transforming traditional workflows. The Director's Lens represents an initial effort to leverage VR technology to enhance the CGI shooting process by assisting filmmakers with camera composition [Lino et al. 2011]. The system integrates an intelligent and automated cinematography engine capable of generating optimal camera placements for shooting. This approach has the potential to streamline CGI filmmaking, introducing an innovative workflow that combines human creativity with automated intelligence interactively and collaboratively. More recently, He et al. further developed the idea of supporting and enhancing the filmmaking creative process by proposing Cinemassis [He et al. 2024]. This tool automatically generates a variety of cinematic composition proposals leveraging user-selected animation keyframes and input semantics, at both keyframe and scene levels, which users can incorporate into their workflows.

Kim et al. proposed a pre-visualization tool to assist screenwriters and filmmakers in simulating stories as 3D animated scenes featuring virtual characters in a digital environment [Kim et al. 2021]. By processing scripts created with the Final Draft screenwriting software, the system utilizes a combination of deep learning, data-driven techniques, and rule-based approaches to analyze and extract key elements such as actions, characters, and dialogue. The output comprises automatically generated pre-visualized animations depicting natural character behaviors and realistic dialogue scenes. The authors further developed the proposed system to provide additional outputs, including a 2D storyboard, an immersive VR-based scenario, and simulations of potential use cases [Kim et al. 2024].

Li and Yu proposed a novel approach to generate virtual activity snippets, which comprise sequenced keyframes of multi-character, multi-object interaction scenarios in 3D environments, by learning from recordings of human-scene interactions [Li and Yu 2023].

Evin et al. developed an open-source, semi-automated cinematography toolset designed to procedurally generate in-game cutscenes that emulate the visual style of a specific film director [Evin et al. 2022]. The system integrates real-time cinematography automation with an innovative timeline and storyboard interface for design-time adjustments. This allows cutscenes to dynamically adapt based on the game state, ensuring a more fluid and responsive storytelling experience.

Manuri et al. proposed a novel storyboarding pipeline to automatically generate storyboards, including detailed camera information and a textual description of the events in each scene, starting from a 3D scene [Manuri et al. 2023b]. Users can create storyboards by selecting actors, choosing available actions, positioning the camera within the 3D environment, and capturing screenshots to save vignettes of the storyboard. The corresponding descriptions are generated based on the actors' actions and statuses. This pipeline has been developed as a 3D desktop application for tabletop storyboarding targeted at experienced and novice storyboard artists, whereas further developments for XR are discussed in [Manuri et al. 2023a].

The analysis of the state of the art depicts a plethora of heterogeneous research projects aimed at exploiting recent advancements in XR and AI to benefit storyboarding and filmmaking, proving the relevance of the research domain and the absence of a singular research approach. This research proposes a novel paradigm to create storyboards in XR, leveraging the capabilities of object-detection and pose-estimation systems to include real-world elements as interactable elements in the virtual scenario. To the best of the authors' knowledge, this is the first system that envisions this paradigm to create storyboard panels based on virtual objects and characters anchored to the physical space on a $1:1$ scale.

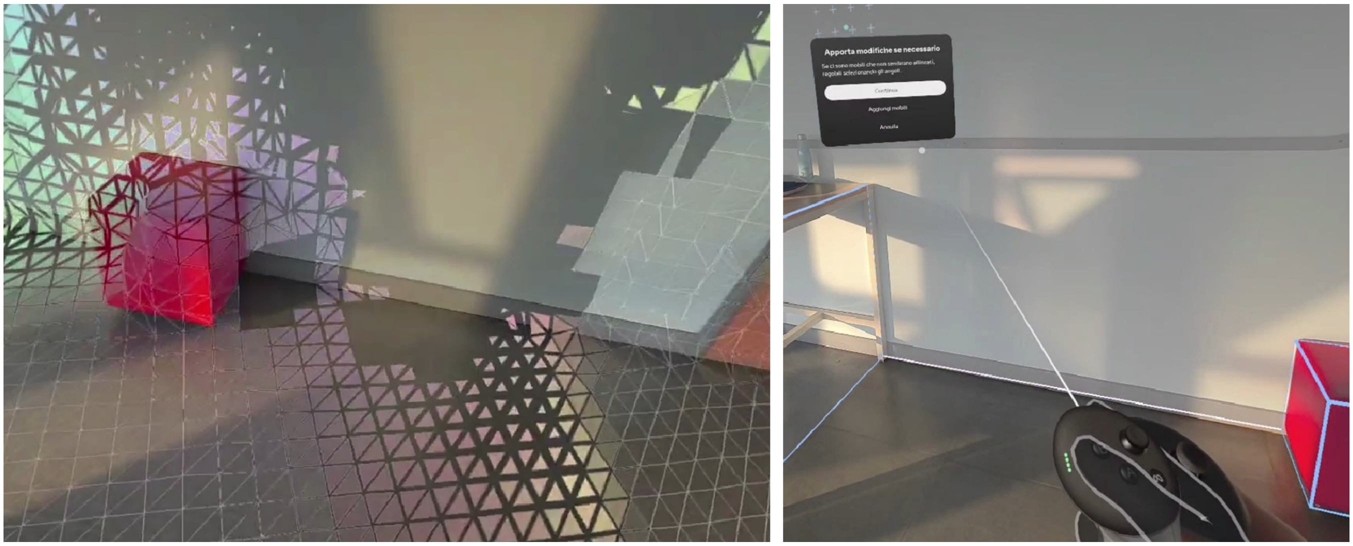

Figure 2: An example of a physical environment scan (left). After the scan, the user can update the bounding box labels corresponding to physical objects of interest (right).

3 The Proposed System

The proposed system is based on previous research investigating storyboarding in extended reality. More specifically, the functionalities to be developed have been defined by referring to the MoSCoW analysis [Tudor and Walter 2006][Hatton 2007] described in [Manuri et al. 2023a] and the user assessment described in [Manuri et al. 2023b]. As a result, the application should guarantee the following main functionalities:

- To insert and remove objects and characters in the scene, choosing from a library
- To create screenshots of the scene to represent the storyboard panels, with a preview of the final storyboard
- To preview what will be framed into the screenshot
- To specify the duration of an action or panel

Moreover, the system has been designed considering the experts' feedback and the application's workflow described in [Manuri et al. 2024]. The proposed system relies on the following steps:

(1) Scanning the physical environment
(2) Setting up the virtual stage with 3D assets and characters
(3) Creating the storyboard by posing the characters with a scene-enacting approach

Framing the scene from the user's point of view (PoV) to create the storyboard panels, freely exploring the 3D space, and trying out different camera shots are requirements that have been prioritized by domain experts. Compared to previous works, the first step is enhanced by relying on the physical environment and envisioning the interaction between real and physical objects. The system relies on 3D models and animation libraries for virtual objects.

Using the physical environment as the starting point for creating storyboards from a 3D scene offers several advantages. The first one is to speed up the scene creation: other 3D storyboarding solutions require users to prepare the virtual stage from an empty scene. Thus, users will either add a limited number of objects or spend much time setting up a rich scene. The proposed approach favors the usage of real-world scenarios. Users need to configure interactable physical objects and add virtual ones.

Another advantage is to fill the gap between 2D storyboard and 3D pre-vis: even the most skilled storyboard artists can only create an approximate representation of a camera shot, and accurately scaling objects without absolute references in cinematic productions or 3D references in CGI productions is another potential source of error, making precise visualization difficult. A storyboard including the real world will help minimize the discrepancies between a 2D representation and the final 3D scene. It can provide a more accurate and valid reference for creating pre-visualizations. This aspect can be very relevant for production that relies on indoor scenes for multiple episodes, such as TV series, or for production that includes existing outdoor environments. Finally, this approach may pioneer a combined storyboarding/pre-visualization solution that allows creating storyboards in extended reality and then animating characters to obtain the pre-vis.

3.1 Physical Environment Scan

Before creating the storyboard, the user must define the physical space in which the storyboard will take place. This phase requires the user to determine the physical environment's virtual bonds and define the physical objects of interest. The proposed system relies on the native "boundary setup" feature provided by the Meta Quest 3 settings. First, the user sets the floor height by pushing a textured grid to the ground with the controller. Then, the user walks the room (or rooms) of interest while the device reconstructs a 3D mesh of the environment. When all the zones of interest have been mapped, the system converts the 3D mesh into planes corresponding to the walls and doors, and bounding boxes corresponding to bulky objects, as shown in Figure 2.

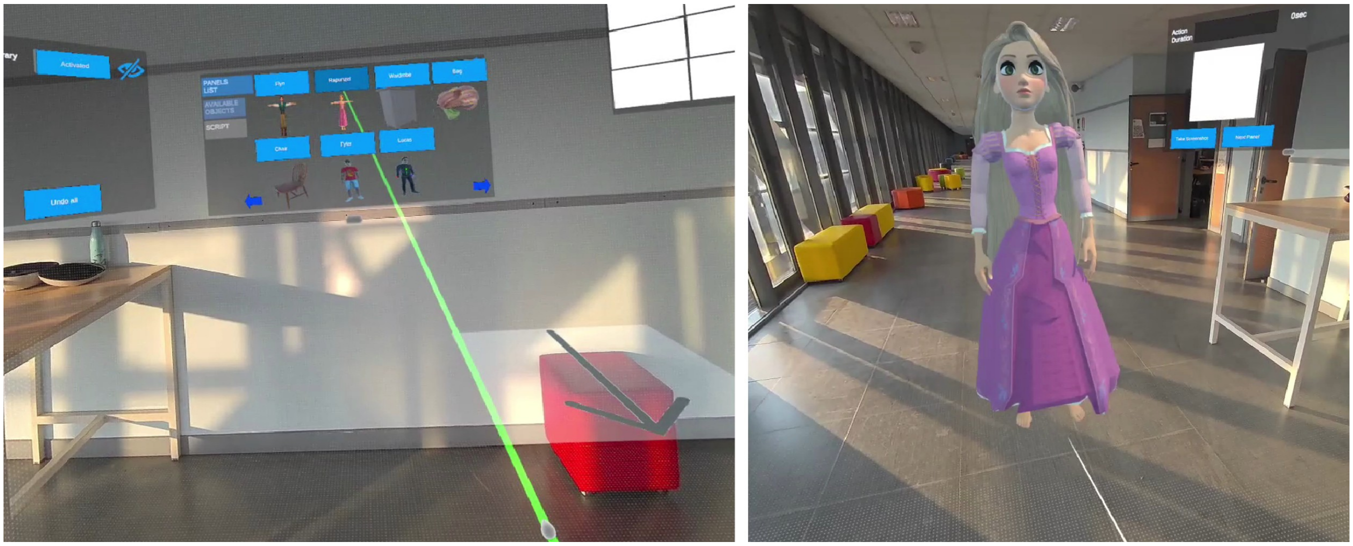

Figure 3: The user can select 3D objects and characters from the library (left) and anchor them to real-world coordinates (right).

Then, users can correct the dimensions and positions of both planes and bounding boxes to replicate the physical space accurately. This native feature has been designed to display precise boundaries in virtual reality applications and avoid harming users. Thus, users are asked to define the position of any other object of interest for their script, regardless of their dimension: this happens by manually adding additional bounding boxes by defining their width, height, and depth by the controllers. Multiple environment scans can be stored on the device.

Once the environment scan is available on the device, the user can start the storyboarding phase, and all the detected bounding boxes and the labels defining the recognized objects will be visible. However, the scanning environment feature can recognize only ten object classes (bed, ceiling, couch, desk, floor, lamp, plant, screen, wall, window). Thus, the user has to manually update the labels of all the physical objects that should be "interactable" for the virtual characters: the selection of a label will show a list of alternatives to choose from based on the script's content. An interactable object is a target object necessary to trigger a character animation; for example, a chair for a "sit down" animation. Additionally, interactable objects may need the definition of a reference plane: reference planes are used for positioning virtual objects in the scene (e.g., virtual objects on top of physical desks) and for animations combining physical and virtual elements: as an example, chairs allow storyboard artists to define the seat height to beautifully blend the graphical appearance of a virtual character sitting down on a physical chair.

3.2 Virtual Elements Setup

Once the physical environment has been mapped correctly in a virtual one, users can focus on the script and add the necessary virtual elements to the scene. A virtual panel available to the user will contain the script, allowing the user to check the object needed to create the storyboard. Another panel shows the library of virtual elements available. Based on what the user wants to frame in the storyboard panel, it is possible to add (or remove) any virtual element from the scene by selecting it from the library panel and pointing to the physical space it should occupy, as depicted in Figure 3.

Then, users can further refine the position and rotation of a virtual element using the controllers. Users can freely switch between the storyboarding and virtual element setup phases. This feature has been introduced to enhance a more flexible and customizable virtual environment, favoring situations that require objects (or characters) to be added (or removed) from the scene in subsequent storyboard panels.

3.3 Storyboarding Phase

The storyboarding phase is based on the enacting paradigm proposed by Manuri et al. [Manuri et al. 2023b], which gives complete control over the actions performed by the characters to generate the panel description automatically. Users can select the available characters in the scene and perform actions chosen from a list. Actions are defined in a text file based on the script to enact (e.g., walk, run, sit down, stand up, etc.). For each action, a corresponding 3D animation is provided. The actions available to a character depend on their status and the context. For example, a standing character near a chair can sit down, and a character sitting on a chair can stand up. When the user selects an action, the corresponding animation is played. The user can pause the animation to obtain the desired character pose, as shown in Figure 4.

Then, users can move in the environment and take a shot of the scene from their PoV, enacting the camera themselves. The camera shot and the automatic description generated by the system are visible in the Current Frame panel. Users can undo actions, repeat them, and take new camera shots until they are satisfied with the current frame. Pressing the "next frame" button, the current

Figure 4: The user can define a character's pose by selecting an available action (left) and pausing the corresponding animation at the desired frame (right).

frame will be finalized, thus adding it to the storyboard and making it visible in the Storyboard panel. The Current Frame panel also allows users to define a length for the given frame on a 1 to 5 scale. Moreover, users can decide with a dedicated button if the actions performed by the characters are consecutive or take place simultaneously. This option will affect the automatic generation of the textual description.

3.4 Technologies

The Unity Engine has been used to develop the proposed application [Unity Technologies 2025a]. Unity is a 3D development engine providing tools to create and operate real-time interactive experiences and deploy them to a wide range of devices, including most of the leading AR and VR commercial devices [Unity Technologies 2025b].

The Meta Quest 3 by Meta has been chosen as the target XR device [Meta 2025a]: it is compatible with both mixed reality and immersive experiences thanks to 2 RGB cameras that provide 18 Pixels per Degree full-color pass-through resolution over a 110°horizontal Field of View (FoV). The pass-through approach allows the user to view the surroundings enhanced with virtual objects as part of the physical space. Even if other AR devices, such as Microsoft HoloLens 2 or Magic Leap 2, offer native pass-through, implying a clearer view of the real world, these devices usually provide a limited horizontal FoV (less than 50°) for the virtual content, thus significantly hampering the interaction with and the visibility of both 3D assets and the user interface. The proposed system relies on the following Unity packages and libraries: OpenXR, the XR Interaction toolkit, and AR Foundation. OpenXR is an open standard that provides cross-platform, high-performance access to XR platforms and devices, enabling applications and engines to run on any system that exposes the OpenXR APIs. The Unity OpenXR Meta package allows users to build mixed reality applications for Meta Quest devices by supporting Meta's OpenXR extensions. The XR Interaction Toolkit is a high-level, component-based interaction system for creating VR and AR experiences. The AR Foundation package enables users to develop multi-platform augmented reality apps, leveraging the peculiarities of each target deployment device.

4 System Evaluation

Three usability experts, selected among scholars from the Department of Control and Computer Engineering of the Politecnico di Torino, evaluated the proposed application. The user's research activity is mainly related to human factors, extended reality, and computer animation; they have at least three years of experience in this research field. Usability experts have been recruited following the arm's length principle, and they are not and have not been involved in any collaboration with the authors.

This evaluation is based on the Nielsen and Molich approach, which demonstrated that combining evaluations from three to five experts is an effective method for identifying and addressing most usability issues in a system or interface [Nielsen and Molich 1990]. The scope of this evaluation is to ensure that, concerning usability, the proposed system is suitable for creating extended reality storyboards.

4.1 Metrics

Feedback from experts was collected in two ways: comments provided while testing the application and a written evaluation based on Nielsen's heuristics [Nielsen 1994]. Experts rated the system for each heuristic on a 1-to-5 Likert scale.

4.2 Test Procedure

The test procedure consisted of the following steps:

(1) Introduction to the system: usability experts were introduced to the proposed research and the test procedure

(2) Written consent: participants gave their written informed consent to participate in the test
(3) Tutorial: users were introduced to the application by a tutorial that describes the main functionalities of the application
(4) Exploration: users were given ample time to explore and test all aspects of the system
(5) Storyboarding: users worked on the proposed use case, creating a storyboard for the given script
(6) Questionnaire: users evaluated the system over the ten Nielsen's heuristics
(7) Open questions: users provided feedback regarding the overall experience

4.3 Use Case

The use case involved creating a storyboard based on a short extract from the Entangled animation script.

4.4 Results and Discussion

Table 1: Usability experts' evaluation for Nielsen's heuristics.

Nielsen's Heuristics	U1	U2	U3	AVG
Visibility of System Status	5	4	4	4.33
Match Between Systema and the Real World	5	5	5	5.00
User control and Freedom	3	3	4	3.33
Consistency and Standards	4	5	3	4.00
Error Prevention	3	4	4	3.67
Recognition Rather Than Recall	4	3	4	3,67
Flexibility and Efficiency of Use	5	3	4	4.00
Aesthetic and Minimalist Design	5	5	4	4.67
Recognize, Diagnose, and Recover from Errors	4	4	4	4.00
Help and Documentation	4	4	4	4.00

Usability experts assessed the proposed application positively. Table 1 shows the users' evaluation of Nielsen's heuristics. All the metrics obtained an average score above three, and seven out of ten received a score of four or more, meaning that the proposed application fulfills the heuristics with an equivalent score between good and optimal. The lower scores for heuristics three, five, and six are due to the number of functions mapped over the controller buttons; experts agree that simplifying the control mapping would improve user control and error prevention. This complies with domain experts' feedback, since navigating a physically enhanced previsualization through an extended reality headset with a natural interface can be a valid alternative or complement to traditional desktop-based approaches. To this end, the user interface could be further enhanced to improve user feedback about the actions performed within the application and the system's status. Afterwards, it will be possible to involve both domain experts and students from filmmaking-related disciplines in the system evaluation.

4.5 Limitations

In its actual version, the main limitation of the proposed system is that the physical environment scan phase is separated from the storyboard phase. Thus, it is not possible to track changes to real objects, implying that they cannot be moved while creating the storyboard. Similarly, the system cannot track opening doors, drawers, and other similar interactions with physical objects. To overcome this limitation, we plan to integrate the environment scan phase into the application, enabling the system to track interactions and modifications to physical objects by exploiting the Scene API provided by Meta [Meta 2025b] and eventually integrating other object detection and pose estimation systems into the proposed application.

Compared to virtual storyboards, relying on the physical world also implies some limitations: firstly, it is not possible to try different virtual lighting setups on real objects, as it is necessary to rely on real-world illumination; this approach implies a more realistic preview but may require additional time to set up the physical space to try out different illuminations. Moreover, compared to desktop-based VR solutions, it is not possible to define multiple cameras and their properties. Still, based on experts' feedback, this limitation is counterbalanced by the user's freedom and simplicity in exploring the scenario and framing the scene by the user's PoV, including real elements in the storyboard panels.

5 Conclusions and Future Work

This research proposes a novel paradigm to create storyboards in XR, leveraging the capabilities of object-detection and pose-estimation systems to benefit the storyboarding phase of a movie production. An application has been designed and developed to create 3D storyboards on a real scale within a physical environment and all its furniture. Wearing a head-mounted display for XR, users can move in the physical space, enrich it with virtual elements and characters, and frame the environment to obtain storyboard panels that mix real and virtual elements. The proposed system has been tested to assess its usability, and initial findings indicate that it allows users to create storyboards in extended reality effectively. Future works will aim to improve the user interface, exploiting the feedback provided by the testers, and integrate the environment scan phase into the application, enabling the system to track interactions and modifications to physical objects. Then, it will be possible to carry out an evaluation procedure involving professional storyboarders to gather additional feedback based on their experience as experts in the field. Finally, students from the master's degree program in Computer Engineering (Graphic and Multimedia learning path) or the master's degree program in Cinema and Digital Media Engineering will be involved in the system evaluation. This evaluation will allow us to measure relevant performance metrics and perform a statistical analysis. The system usability and the task workload will be measured using the System Usability Scale (SUS) [Brooke et al. 1996] and the NASA Task Load Index (NASA-TLX) questionnaires [Hart and Staveland 1988], as well as the Creativity Support Index [Cherry and Latulipe 2014], comparing the proposed system with other renowned approaches and AI-based storyboard solutions.

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