



International Commission on Illumination
Commission Internationale de l'Eclairage
Internationale Beleuchtungskommission

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DOI 10.25039/x051.2025/jvo6s2

This article is also published as part of:

Proceedings of the CIE 2025 Midterm Meeting Vienna, Austria, July 4-11, 2025:
Scientific Conference (July 7-9, 2025)

DOI 10.25039/x051.2025

in

Proceedings of the CIE (International Commission on Illumination)

ISSN no. 3061-015X (print), 3061-0168 (online)

The paper has undergone double-blind peer review and its final version has been presented at the CIE 2025 Midterm Meeting, Vienna, Austria, July 4–11, 2025.

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INFLUENCE OF LEVEL OF DETAILS OF 3D OBJECTS ON REALISM IN VR ENVIRONMENTS

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Abstract

Rendering high levels of detail (LOD) in virtual reality (VR) requires extensive 3D modelling, which is computationally intensive and often requires high-end hardware. These demands frequently lead to compromises in performance, resulting in lower frame rates, inconsistent graphics, and system lag, which reduce immersion and increase the risk of motion sickness. To address these challenges, this study explores perceived realism rather than solely pursuing photorealistic rendering. The goal is to identify the most important visual features for maintaining realism in VR environments without significantly increasing the computational load. An experiment was conducted to examine the impact of the LOD on the perception of realism. Participants evaluated VR spaces in which virtual human models with different LODs were placed. The results indicated that the LOD of objects is the dominant factor in perceived realism. But other visual cues such as shadows would affect perceived realism when the LOD is low.

Keywords: Virtual Reality, Level of Detail, Realism, Display, Style transfer

1 Introduction

1.1 Background

With the commercialization of head-mounted displays (HMDs), virtual reality (VR) technology is becoming more accessible to the public and expanding its potential user base. VR technology is also used in the building and construction sector. Photorealistic rendering techniques are now available. However, achieving realism in VR through photorealistic rendering requires high computing power and detailed 3D modelling. This requires a computer with a high-performance graphics processing unit, which tends to be expensive. Level of detail (LOD) plays a key role in the pursuit of geometric realism in VR, because users tend to judge realism by comparing virtual objects to real objects. Increasing the LOD increases the number of polygons but often reduces HMD performance in terms of latency and frame rate, which reduces the immersive VR experience.

Technological advancements continue to improve graphical fidelity. However, the user experience in VR depends not only on rendering quality but also on how humans perceive and interpret visual cues. Jicol et al. (2023) noted that presence is determined by technical and human factors in VR and emphasized that it is not yet fully understood how technical factors such as visual realism and the field of view interact with human factors such as emotions and agency (a user's perceived ability to influence and control elements within a virtual experience) in the formation of presence. Even an environment that looks detailed or real may feel unnatural if it does not match the way users expect to see and interact with things. This means that realism in VR is not simply about enhancing visual detail, but about meeting users' perceptual expectations. Understanding these subtle interactions between technology and perception is essential to designing more immersive and efficient VR systems.

These technical limitations raise questions about the need for full photorealism, especially for VR-HMDs for the general consumer. Perceived realism — user's subjective sense of realism — may be a more efficient and practical goal for development of VR systems. This study focuses on the perception of realism in VR environments rather than on photorealistic rendering. As a

starting point, an experiment was conducted to examine how people perceive realism when viewing objects with different LODs.

1.2 Related work

Realism in VR environments is increasingly recognized as a subjective experience rather than simply a matter of photorealistic rendering. Realism is defined by a dictionary as "*the quality of being or seeming real*" (Longman Dictionary). It implies that what matters most is the user's perception of authenticity rather than technical precision.

In the context of VR environments, it is often not realism itself that plays the most important role in shaping an immersive experience, but how realistic the environment feels to the user. As Nilsson et al. (2017) argued, perceived realism, rather than purely visual accuracy, is essential to support the user's sense of immersion and presence in a VR environment. They described perceived realism as the user's subjective impression of how realistic an environment appears. Their study questioned the necessity of achieving full photorealism in the VR environment, suggesting that perceived realism may be more crucial for immersive experiences. Similarly, Weber et al. (2021) challenged the current definition of presence in VR, emphasizing that perceived realism is central to the user experience but is often overlooked in theoretical models. Taken together, these perspectives highlight the possibility that matching users' cognitive expectations may be more important in creating immersive experiences than aiming for complete photorealism.

Jicol et al. (2023) also explored the concept of realism in VR. They stated that visual realism and the frame rate of the HMD are important factors in enhancing presence. Visual realism was divided into two main components: geometric realism and illumination realism. These were further divided into quality of objects and terrain, texture and lighting, and shadow quality. Within this framework, the LOD was considered to contribute significantly to geometric realism. The higher the LOD, the more realistic the object appears. However, despite technological advancements, most current VR systems, especially commercially available ones, are still limited in their ability to faithfully reproduce real-world sensory stimuli, interactions, and behaviours. This gap highlights the importance of focusing on perceived realism rather than pursuing only photorealistic rendering to create an immersive and efficient VR experience.

1.3 Research gap

Most existing VR research continues to pursue full photorealism in virtual environments, often requiring significant computational resources. And there is little research on how perceived realism can be achieved without relying on high-fidelity rendering. This study addresses this gap by examining visual factors of VR environments that affect perceived realism. Possible visual factors are: (1) lighting and shadows, (2) object material and texture, (3) level of geometric detail, and (4) motion and interaction. First, this study focused on the LOD of objects to understand how visual simplification affects perception. Ultimately, this study will explore more efficient and flexible approaches to achieving perceived realism without the need for computationally intensive photorealism.

2 Experiment on perceived realism

2.1 Experimental conditions

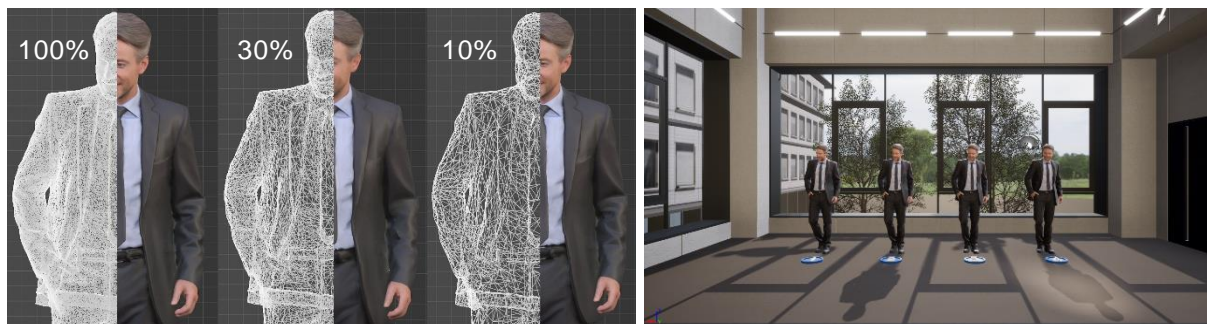
Gaining insight into how people interpret realism can help to optimize the visual quality of the VR environment while balancing computational efficiency. The experiment used a virtual human model as the test object. Human models are well suited for evaluating subtle changes in realism because of their familiarity and complex shapes and textures. In addition, factors such as lighting, shadow, and rendering performance were considered for the experimental conditions.

A virtual replica of an actual room was created, and virtual human models were placed. Three conditions were set for the LOD of the virtual human model: 10%, 30%, and 100%. Figure 1 (a) shows the virtual human models with different LODs. Table 1 shows the number of elements of the virtual human model calculated in Blender, an open-source 3D computer graphics software tool. Four virtual human models with different LODs were placed in one experimental condition.

Four conditions were set for shadow condition: natural, soft, and unnatural shadows, and shadowless condition. Figure 1 (b) shows the shadow conditions. An environment without shadow serves as a baseline for evaluating absence of depth. Natural shadows represent real-world situations and mimic how shadows and lighting inherently behave. Soft shadows allow exploration of how subtle shadow softness influence perception. The unnatural shadow conditions was used to assess participants' sensitivity to anomalies. This perspective was adopted by reference to a previous study that mentioned unrealistic shadows decrease perceived realism (Boyce, 2003).

From these LOD and shadow conditions, five VR space conditions were set up as follows:

- Mixed LOD condition: one 100% LOD, one 30% LOD, and two 10% LOD human models
- Low LOD outlier condition: one 10% LOD human model placed among three 100% LOD human models
- High LOD outlier condition: one 100% LOD human model placed among three 10% LOD human models
- Low LOD shadow condition: Four human models with 10% LOD under different shadow conditions
- High LOD shadow condition: Four human models with 100% LOD under different shadow conditions



(a) Virtual human models with different LODs

(b) Shadow conditions

Figure 1 – Experimental conditions

Table 1 – The number of elements of the virtual human model

LOD	Vertices	Edges	Faces	Triangles
100%	50 025	149 981	99 962	99 962
30%	15 035	45 017	29 988	19 988
10%	5 031	15 020	9 995	9 995

The virtual replica of an actual room was generated in Blender. It was exported to Unreal Engine 5.0.3 to create the VR space. Outdoor elements such as trees and buildings were intentionally positioned far enough outside the virtual space to avoid casting shadows that might overlap or interfere with the shadows of the virtual human models. This setup was designed to maintain controlled shadow conditions for the purpose of assessing realism.

2.2 Experimental procedure

A Meta Quest 3 HMD was used for the experiment. The simulation was run on a desktop with the specifications of an AMD Ryzen 7 5800X processor with 64 GB of RAM. Participants observed the virtual human models in the VR space and completed a questionnaire about perceptions of realism and preferences. They were able to move within a 2 x 2 m boundary of the virtual space and teleport to any location they wanted during their observation. Figure 2 shows how the virtual space and virtual human models looked inside the HMD.

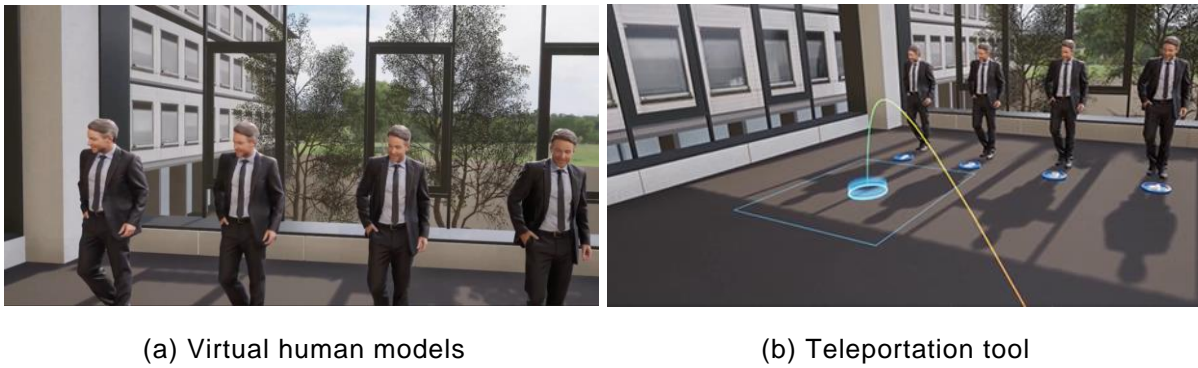


Figure 2 – Actual condition inside the HMD

The questionnaire consisted of three sections. In the first section, participants were asked to identify the most and the least realistic human models. They were allowed to select more than one human model. In the second section, they rated the realism of four human models using a 5-point Likert scale (e.g., 1 = least realistic, 5 = most realistic). In the last section, they were asked what aspects of the VR space contributed to their perception of realism. All questions were presented while the participants were immersed in the VR space. Participants were not provided with a strict definition of realism and were encouraged to make judgments based on their natural perception of what felt most real. Eighteen participants in their 20s assessed the realism of the VR space.

2.3 Results and discussion

In the mixed LOD condition, the participants were asked to choose the most realistic human models based on their subjective impressions, and a total of 20 votes were obtained. The 100% LOD human model received 13 votes (65%). The 10% LOD human models received 5 votes (25%), more than the 2 votes (10%) for the 30% LOD human model. This can be attributed to the fact that there were two 10% LOD human models in this condition. But it can also be said that the 10% LOD and 30% LOD human models are hardly distinguishable. Figure 3 shows the results of the realism evaluation in the mixed LOD condition. As expected, the 100% LOD human model was rated as the most realistic.

The higher the LOD, the more realistic the human model was rated. However, some participants rated the 10% LOD human model as highly realistic. In a case like the mixed LOD condition, people tend to choose a realistic object based on their relative evaluation. In a VR environment with only low LOD objects, people may rate them as realistic. This suggests the possibility of creating a convincing VR experience without maximizing object complexity and detail reproduction.

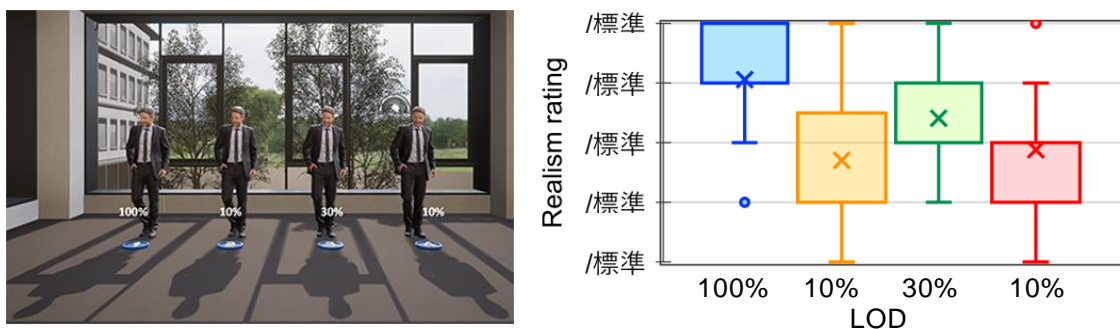


Figure 3 – Realism ratings in the mixed LOD condition

In the low LOD outlier condition where one 10% LOD human model was placed among three 100% LOD human models, 27 of 30 votes rated the 100% human models and 3 of 30 votes rated the 10% LOD human model as the most realistic. But only 3 of the 18 participants chose all three 100% LOD human models. Most of the participants chose one or two 100% LOD human models. This suggests that objects with low LOD are more likely to be perceived as less realistic

when they are among objects with high LOD, but the perceived realism is ambiguous. Figure 4 shows the results of the realism evaluation in the low LOD outlier condition. All three 100% LOD human models were consistently rated as highly realistic.

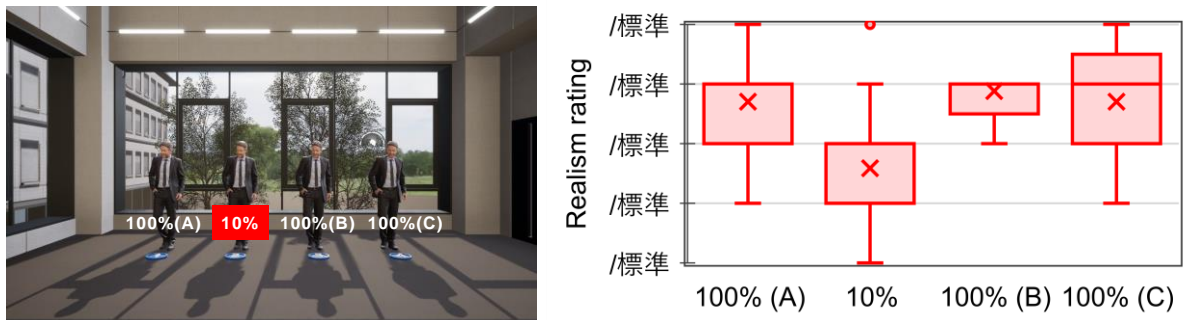


Figure 4 – Realism ratings in the 10% LOD outlier condition

In the high LOD outlier condition where one 100% LOD human model was placed among three 10% LOD human models, 13 of 22 votes rated the 100% LOD human model as the most realistic. Participants easily identified the 100% LOD human model. But one participant judged all four to be the most realistic. Figure 5 shows the results of the realism evaluation in the high LOD outlier condition. The 100% LOD human model was rated as very realistic, while the ratings for the 10% LOD human models varied. This suggests that the perception of realism for objects with low LOD is more context-dependent and less predictable.

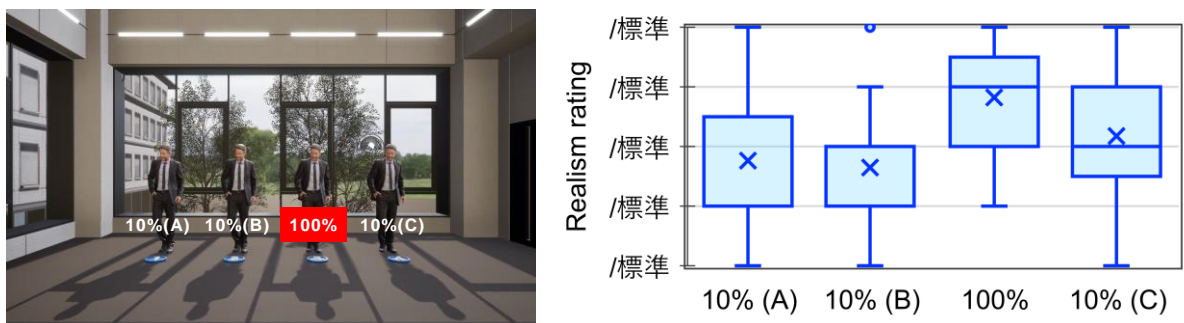


Figure 5 – Realism ratings in the 100% LOD outlier condition

In the low LOD shadow condition, the natural and soft shadow conditions resulted in a moderate level of perceived realism, while the unnatural shadow condition and the shadowless condition reduced the perceived realism (Figure 6). Since soft shadows mean that the light coming in is weak, participants probably did not feel so strange about the soft shadow. Considering the results of the three experimental conditions for the LOD, the unrealistic shadow condition, in addition to the low LOD, must have lowered the perceived realism.

In the high LOD shadow condition, all shadow conditions resulted in a relatively high level of perceived realism (Figure 7). It indicates that the LOD of objects is the dominant factor in perceived realism. Interestingly, the ratings of the shadowless human model varied widely. Although shadows can have a subtle influence on the perception of realism, the participants probably focused primarily on the quality of object details when evaluating the high LOD human models.

The choice of the most realistic human models was independent of shadow conditions for both of the low LOD and the high LOD conditions. It remains unclear whether the participants were fully aware of the differences in shadows. However, the results suggest that people rely more on environmental cues to assess realism when object detail is limited. It can be said that shadows play a more influential role in shaping perceived realism when objects lack visual complexity.

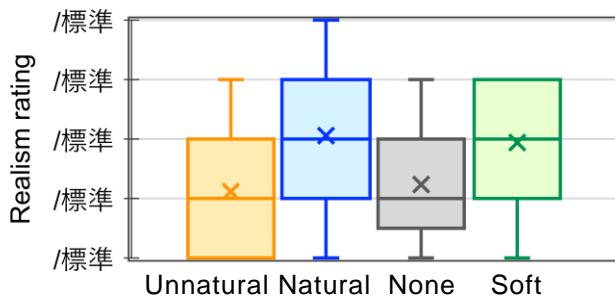
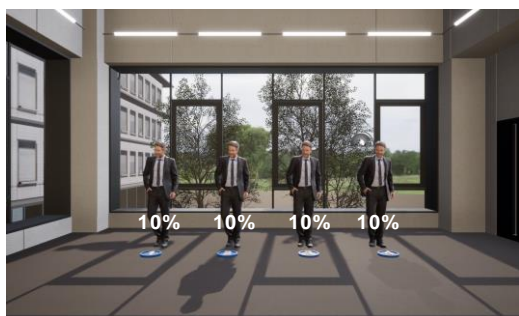


Figure 6 – Realism ratings in the 10% LOD shadow condition

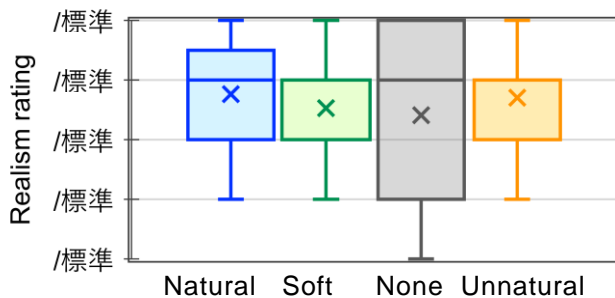
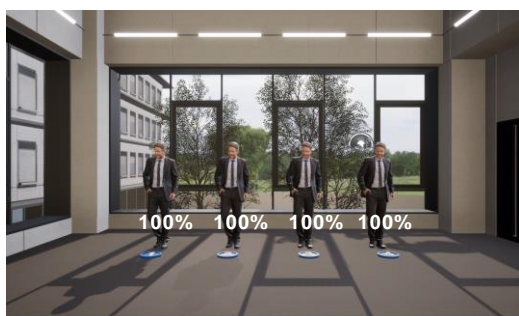


Figure 7 – Realism ratings in the 100% LOD shadow condition

3 Conclusion and outlook

In order to identify visual factors essential to the perception of realism in VR environments, this study first conducted an evaluation experiment on the LOD and shadow conditions. In the condition with three different LODs, it was found that the higher the LOD, the higher the perceived realism. In the outlier conditions where one virtual human model with a different LOD was mixed, relative contrast was found to affect the perceived realism. It was also suggested that the perception of realism for objects with low LOD is context dependent. Finally, in the shadow conditions, the role of environmental context was explored. The impact of shadows on the perception of realism was large, especially when object fidelity was low. Environmental elements of a space act as visual cues and play an important role in defining the realism inside the VR environment.

The results of this study showed that participants often associated realism with the LOD, and they particularly preferred virtual human models with high LOD. Participants correctly rated the LODs in a relative context and the majority of them were able to detect the virtual human model with a different LOD from the others. This reinforces the idea that contrasts in visual fidelity play an important role in shaping perceived realism.

In contrast, the shadow condition, even when visually noticeable, did not appear to significantly affect participants' judgments of realism. Many participants seemed to evaluate the realism of the virtual human models based on their fidelity rather than environmental accuracy. But it is worth noting that in the low LOD situation, realistic shadow conditions enhanced perceived realism more than unrealistic shadow conditions. This suggests that realism of the VR environment can be achieved by making the light and shadow conditions realistic, even with low LOD objects.

However, the results for the 10% LOD human model implies the influence of visual cues that are not yet examined. There was ambiguity in the perception of realism. Understanding the gray areas in judgments will provide the basis for future research into balancing VR system performance and perceived realism. Realism in VR environments can be optimized not only by

increasing the level of geometric detail but also by strategically manipulating subtle visual features that affect perception.

Future studies will explore additional perceptual cues other than LOD, such as texture quality, edge sharpness, and object motion. A key direction involves investigating the role of style transfer as a tool to optimize perceived realism without relying on photorealistic rendering. Style transfer is a machine learning technique that creates a new image by combining the content of one image with the style of another image. By selectively enhancing or simplifying certain visual features, style transfer may make it possible to create immersive VR environments while reducing computational load.

Acknowledgments

This study was supported by JSPS KAKENHI Grant Number JP23K04140.

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