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Evolutionary Pathways and Effectiveness Assessment of Virtual Reality Visual Communication

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Abstract: This study employs bibliometric analysis to explore publication trends in visual communication tools within Virtual Reality Environments (VRE), using Scopus and Web of Science data and VOS Viewer software for keyword co-occurrence mapping. Findings reveal a shift from 3D modeling to user experience, emotional regulation, and multisensory integration, underscoring VRE's potential to enhance engagement and creativity. Expanding data sources and standardized evaluation frameworks could further improve VRE's applicability in visual communication.

Keywords: Virtual Reality Environments (VRE), Visual communication, User experience .

Background and Unresolved Issues

With the continuous advancement of Virtual Reality (VR) technology, its applications in visual communication have expanded, covering various fields such as teleoperation systems, data visualization, auditory perception, and rehabilitation training (Sun et al., 2020; Zhang et al., 2020; Hayatpur et al., 2020; Salanger et al., 2020). As a highly immersive interactive medium, VR can transport users into a virtual environment with multidimensional perceptions, offering an immersive

experience that far surpasses traditional media. However, conventional qualitative research methods (such as surveys and interviews) fall short in evaluating the effectiveness of VR in visual communication. These methods struggle to fully capture the dynamic changes in multidimensional perception within virtual environments and to provide a comprehensive assessment of its impact on visual communication, particularly in complex interactive effects like emotional regulation and multisensory integration, where precision and consistency are paramount.

While some studies have explored VR's potential in influencing user behavior, emotional experience, and physiological responses, they largely rely on qualitative tools and lack a unified quantitative assessment framework. This limitation results in findings that are not comparable across different application scenarios, making it difficult to establish a systematic standard for evaluating the effectiveness of visual communication in VR. This shortfall hinders the further dissemination and practical application of VR in the field of visual communication.

To address this gap, this study employs bibliometric analysis to establish a standardized evaluation method for quantifying the effectiveness of VR in visual communication.

Literature Review

Previous research in the field of visual communication has primarily focused on how information presentation affects user acceptance and comprehension, typically employing qualitative methods such as surveys and interviews to evaluate user experience feedback through qualitative data. While these early studies have achieved significant outcomes in specific application contexts, such as education and training simulations, they struggle to capture the multidimensional perception and dynamic interactive effects present in VR environments.

With the rapid development of VR technology, researchers have gradually introduced new research methods. For example, Sun et al. (2020) combined mixed reality technology in a teleoperation system, using quantitative collection of physiological and behavioral data to assess users' visual perceptual load. Zhang et al. (2020) applied multisensory interaction technology within the authoring tool FlowMatic to explore the impact of visual and auditory information on user experience. These novel methods provide a quantitative complement to traditional qualitative research, enabling researchers to more comprehensively understand users' multisensory feedback within virtual environments.

In terms of application scenarios, the study by Hayatpur et al. (2020) demonstrated VR's application in the spatial data visualization system DataHop, analyzing the efficiency and accuracy of data transmission through visual effects. Salanger et al. (2020), in a study on children's hearing, used speech perception tests across different scenarios to investigate VR's supportive effect on speech comprehension. These studies showcase VR's diverse applications across various scenarios; however, the lack of a systematic quantitative framework in these studies makes cross-scenario comparisons challenging.

Technological advancements have also propelled emerging research directions in VR visual communication, such as emotional regulation and multisensory experiences. For instance, Lin and Garcia (2022) studied mechanisms of emotional regulation in VR, analyzing the combined effect of visual and auditory information on user emotions. As multisensory interaction technology matures,

such studies show significant potential in enhancing VR user experience; however, the absence of quantitative standards continues to impede the systematic comparison and practical application of these research outcomes.

Overall, despite VR's vast potential across various fields, the lack of a consistent quantitative analysis method renders findings from different application scenarios less universally applicable. Thus, this study aims to establish a unified quantitative framework through bibliometric analysis, providing standardized evaluation tools for cross-scenario research on the effectiveness of VR in visual communication, thereby promoting deeper development in this field.

Research Gaps and Motivation

Despite the widely recognized potential of Virtual Reality (VR) in the field of visual communication, existing studies are still lacking in the establishment of a quantitative analysis framework and lack a unified, standardized evaluation method. This absence of a systematic quantitative framework results in a lack of comparability and generalizability across different application scenarios. For example, although researchers have explored the visual communication effects of VR in fields such as education, medical rehabilitation, and data visualization, the absence of standardized quantitative metrics makes cross-study comparisons challenging, thus limiting the practical dissemination and application of these findings.

Current research often relies on traditional qualitative methods, such as surveys and interviews, which cannot adequately capture complex mechanisms in VR's multidimensional interactive experience, such as emotional regulation and multisensory integration. The lack of quantitative analysis not only impedes the formation of a systematic comparative framework across studies but also restricts interdisciplinary researchers' ability to apply VR across varied contexts. Therefore, establishing a standardized quantitative framework could improve the accuracy of VR visual communication effectiveness research and provide scientific support for cross-scenario applications.

Addressing this gap, this study aims to establish a unified quantitative evaluation framework for the visual communication effects of VR through bibliometric analysis. This framework will enable researchers to analyze and compare the effectiveness of visual communication in VR applications across fields more effectively, supporting future technological development and practical applications.

Research Methodology

This study employs bibliometric analysis to systematically examine publication trends related to visual tools and communication in the field of Virtual Reality Environments (VRE). The research design is based on the Scopus and Web of Science databases, aiming to reveal research hotspots and development directions within this field through a keyword co-occurrence network analysis.

Data Collection and Screening Process：

During the data collection phase, records related to VRE were extracted from the Scopus and Web of Science databases. Keywords such as "Virtual Reality Environments," "visual," "communication," and "tools" were used, and a multi-stage screening process was conducted using keyword combinations

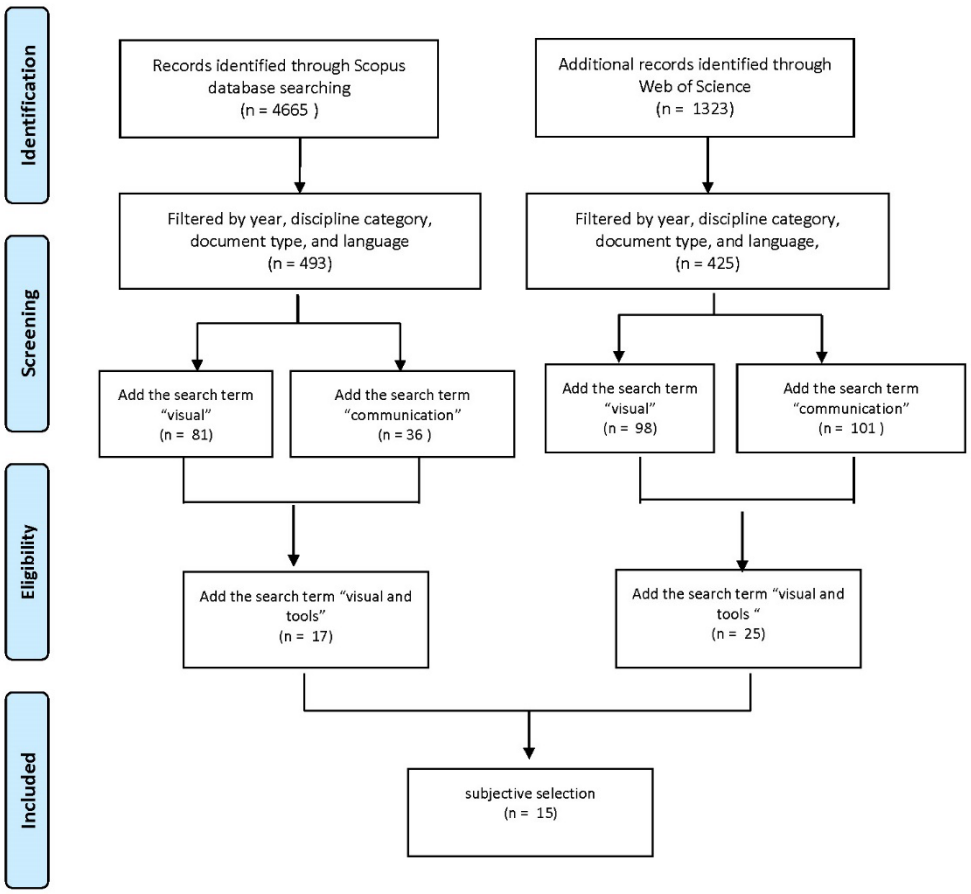
to ensure accuracy and comprehensiveness. The initial screening yielded 4,665 results in Scopus and 1,323 in Web of Science.

To ensure data diversity and coverage, further filters were applied based on time (2014–2025), academic categories (Social Sciences and Arts and Humanities), document type (Articles, Conference Papers, and Reviews), and language (English). After this step, the dataset was narrowed down to 425 articles from Scopus and 493 from Web of Science. In the eligibility screening phase, more rigorous criteria were applied, such as direct relevance to VRE visual communication effects, further refining the core dataset to 15 key articles. The PRISMA flowchart was used throughout the data screening process to ensure transparency and replicability at each stage. (Show as Figure 1)

To further analyze these articles, VOS Viewer software was used to generate a visual map of the keyword co-occurrence network. This map allows for an exploration of international research collaboration patterns and reveals trends in high-frequency keywords and emerging topics within existing literature. Additionally, by integrating the analysis of keywords and co-occurrence networks, this study identifies potential future research directions and key areas, providing scientific guidance for research in the VRE field.

Figure 1

Flow Diagram of Literature Screening for Visual Communication Research in Virtual Reality Environments



Analysis of Research Topics and Trends in Virtual Reality Environments Based on the Scopus Database

This study analyzes keywords from literature in the Scopus database to uncover recent trends in topics related to visual tools and communication within the Virtual Reality Environments (VRE) field. The keyword analysis indicates a shift from a technology-driven focus towards user experience, emotional regulation, and multisensory integration. To clearly illustrate the evolution of these topics, this section provides a chronological analysis of major research directions based on the time distribution of keywords. (Show as Figure 2)

Early Research Topics: 3D Modeling and Agent-Based Simulation

In the early stages, 3D modeling and agent-based simulation were primary research focuses in the VRE field, represented by blue nodes in the keyword co-occurrence network. Early studies concentrated on constructing three-dimensional models and agent simulations within virtual environments to enhance users' cognitive experiences (Bustillo et al., 2015). While these studies laid the groundwork for the design and technical development of virtual scenes, they showed limitations in terms of user experience and multidimensional interaction.

User Research and Virtual Assembly

As VR technology matured, user research and virtual assembly emerged as popular topics in recent years, indicated by green nodes in the network diagram. Researchers began to focus on user behavior and feedback within virtual environments, exploring the impact of VR systems on user cognition and behavior (Etemadpour et al., 2019). Virtual assembly research involves the interaction and integration of components within virtual scenes, which helps improve VR system design efficiency. This phase of research supported the human-centered design of virtual scenes, though attention to emotional and sensory experiences remained insufficient.

Emerging Research Topics: Emotional Regulation and Multisensory Integration

The latest research trends are represented by yellow nodes in the VOS Viewer network diagram, focusing on emotional regulation, multisensory integration, and audiovisual experiences. Researchers have begun exploring ways to enhance users' emotional experiences by integrating visual and auditory information within virtual environments (Benlamine et al., 2021). Research in emotional regulation examines VR's influence on user emotions and attempts to heighten VR's immersive effect through multisensory experiences. These themes reflect a shift in virtual reality from technology-driven to user experience-oriented approaches.

Consumer Demand Analysis and Marketization Trends

In recent years, with the growing adoption of VR technology in the commercial sector, consumer demand and market analysis have also become research hotspots. Researchers are examining user feedback on VR products and analyzing market demand for VR technology to inform future commercial applications (Chen et al., 2024). This research direction suggests that VR applications are moving from academic exploration towards market promotion.

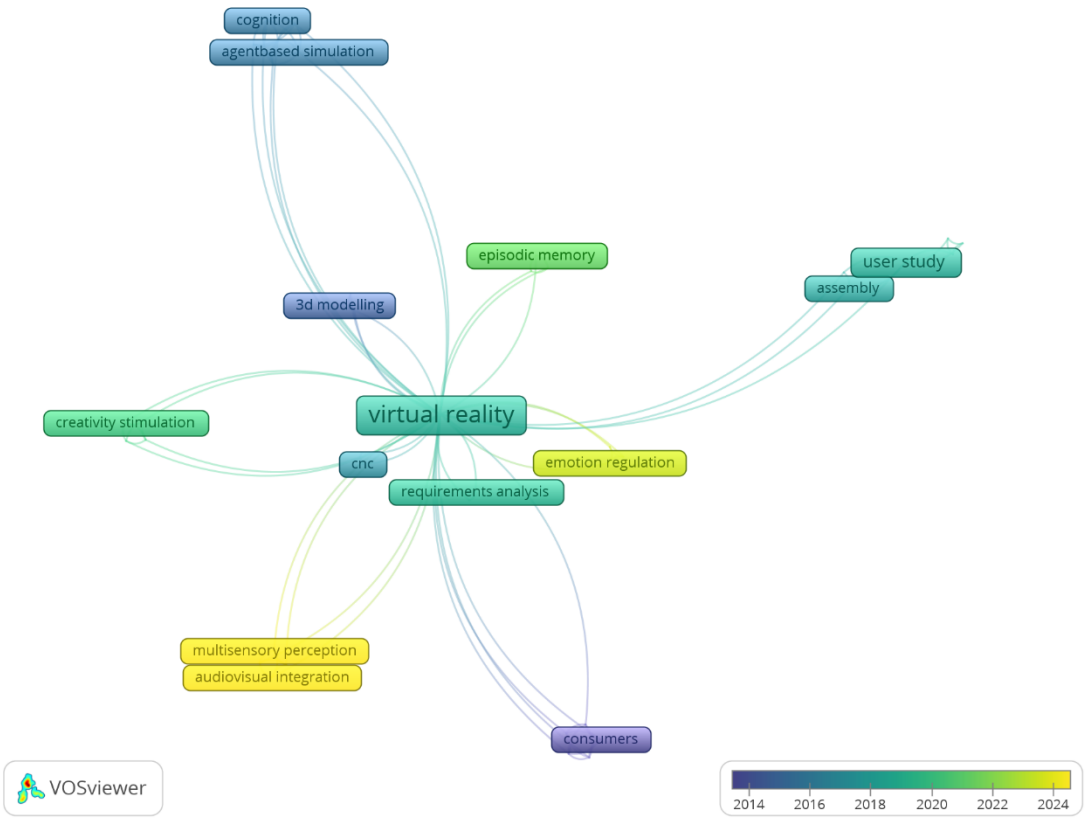
Creativity Stimulation and Educational Applications

Creativity stimulation and educational applications are emerging fields in VR research, represented by the green region in the lower left of the diagram. This research theme explores how VR environments can stimulate users' creative thinking and improve learning outcomes in educational settings (Fleury et al., 2020). This direction highlights VR's substantial potential in education and innovation, suggesting that future research may further expand into instructional design and creativity development.

The time-series analysis of these keywords reveals that research hotspots in the VRE field have gradually transitioned from early topics like 3D modeling and agent-based simulation to user experience and multisensory integration. This trend provides an important theoretical and practical foundation for the further development of VR technology and its cross-disciplinary applications.

Figure 2

Keyword Co-occurrence Network of Visual Communication Research in the Field of Virtual Reality



Conclusions

This study explores the application of visual tools in Virtual Reality Environments (VRE) and examines research trends, highlighting progress and challenges within the field. The analysis indicates a shift in research focus from early technology-driven topics, such as 3D modeling and agent-based simulation, toward a user-centered approach that emphasizes emotional regulation, multisensory experiences, and creativity stimulation. This trend not only showcases current research priorities but also underscores the importance of enhancing user experience and interaction in VRE.

Limitations

Despite its comprehensive approach, this study has certain limitations. First, the data sources are limited to specific academic databases, which may not encompass the latest industry developments and practical applications. Second, the study relies mainly on quantitative analysis, potentially overlooking qualitative insights that are crucial for a deeper understanding of user experience. Furthermore, differences in terminology and classification systems across studies limit the comparability of results, affecting their generalizability in diverse VRE application scenarios.

Future Research Directions

Future research should consider broadening the range of data sources to include industry reports, patents, and user-generated content to capture emerging trends in real-world applications. Combining qualitative research methods could also provide a more comprehensive perspective on VRE user experience. Additionally, developing a unified evaluation standard for visual communication effectiveness would support future research, facilitate cross-study comparisons, and promote further technological advancement. Focusing on these directions would contribute to a deeper understanding of VRE's role in enhancing visual communication and user experience, promoting its widespread application across various fields.

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