

Reframing the sustainability-quality trade-off: The role of social virtual reality in academic conferencing

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Highlights	Abstract
• Social VR offers a well-balanced alternative to on-site and videoconferencing formats in the context of academic conferencing. • It combines ecological and economic sustainability benefits with socially acceptable levels of interaction quality. • Participants reported clear advantages in terms of time savings, reduced travel costs, and flexible, location-independent access. • Shortcomings remain regarding informal social exchange and nonverbal expressiveness, which affect perceived social presence. • Design recommendations are provided to address challenges and support the sustainable implementation of Social VR.	Academic on-site conferences are vital for scholarly exchange and knowledge advancement, yet they contribute significantly to environmental burdens. Considering global sustainability challenges and the limitations of videoconferencing, Social VR offers an immersive alternative that replicates physical conference settings and enables avatar-based interaction. While existing pilot studies have explored perceived benefits and limitations of Social VR, empirical research comparing conference formats with respect to ecological, social, and economic sustainability remains scarce. To address this gap, a mixed-methods study was conducted with participants ($N = 32$) of an academic conference held in a Social VR environment. Data was collected via questionnaires combining validated scales and open-ended items. Results show that 43.8% of participants preferred on-site conferences, 40.6% preferred Social VR, and only 15.6% favored videoconferencing. Reported advantages of Social VR included ecological and economic benefits with socially favorable interaction conditions. These included a stronger sense of presence, more inclusive participation, and greater comfort in communication than conventional videoconferencing. Overall, the findings indicate that Social VR is a promising intermediate option, combining ecological and economic advantages with socially acceptable interaction quality, while leaving specific gaps in informal networking and nonverbal richness to be addressed by future technological and organizational design.
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Keywords: Social Virtual Reality, Academic Conferences, Sustainability, Interaction Quality	

1. Introduction

In today's world, marked by global climate change, declining natural resources, and increasingly threatened biodiversity, sustainable action is essential in all areas of society, including academia. Empirical analyses demonstrate that 80–96% of the CO₂ emissions from on-site conferences result from air travel, with large events generating over 2,000 tons of greenhouse gases or approximately 1.3 t CO₂ per delegate (Burtscher

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et al., 2020; Klöwer et al., 2020; Topp et al., 2024). A recent scoping review further highlights that shifting conferences to online or hybrid formats can substantially reduce their carbon footprint while also lowering resource, time, and energy waste, thus making them eco-friendlier and more inclusive (Leochico et al., 2021). Consequently, moving such events online can therefore significantly reduce their environmental costs (Welch et al., 2010).

However, sustainability (in academic conferencing) encompasses not only ecological concerns but also social and economic dimensions. Key dimensions of social sustainability include participation, equitable access and inclusion, social connectedness, a sense of belonging, and individuals' well-being within social interactions (Holden, 2012; Wolsko et al., 2016), which are closely tied to the quality and spontaneity of interpersonal interaction. Interaction quality also affects economic sustainability, as effective communication facilitates knowledge exchange, collaboration, and productive use of time and human resources. The widely established use of videoconferencing systems poses challenges to both dimensions. It often reduces opportunities for rich social exchange (Bonfert et al., 2023) and it can lead to mental and physical exhaustion, commonly referred to as "Zoom fatigue" (Bailenson, 2021). This not only disadvantages individuals who are more susceptible to cognitive overload, thereby undermining social equity, but also diminishes participants' overall ability to engage effectively, which limits the economic sustainability of such formats.

For this reason, Social Virtual Reality (VR) environments are increasingly being tested as alternatives. Pilot studies indicate a generally high level of acceptance, quality of experience, and satisfaction with such formats (e.g., Ahn et al., 2021; Dyrna et al., 2023; Kirchner & Nordin Forsberg, 2021; Zender & Mulders, 2022). While participant feedback in these studies has occasionally included perceived advantages and disadvantages compared to both on-site and videoconference formats, little research has systematically assessed participants' actual preferences among the three conference types. Moreover, there is limited insight into how participants' perceptions relate to sustainability, and to what extent ecological, social, or economic factors are perceived as more or less reflected across the respective conference types. To address this gap, we conducted a study in which participants of an academic conference held in Social VR were surveyed regarding their format preferences and their perceptions of sustainability-related factors in comparison to academic on-site and videoconference events. The theoretical background, methodology, and results are presented and discussed in the following sections.

2. Literature

2.1. *Relevance and Nature of Academic Conferences*

For several centuries, academic conferences have served as essential venues for knowledge exchange, the dissemination and quality assurance of research findings, agenda setting and the development of networks and collaborations (Hansen & Pedersen, 2018). Social interaction within the academic community plays a central role and is particularly realized through informal exchange. Academic conferences provide opportunities to establish new contacts, maintain existing networks and initiate collaborations (Haus, 2019). Through this process, participants increase their visibility, which is a key resource in academia (Bourdieu, 1993). It is also considered to enhance their social capital (Bourdieu, 1992) and an opportunity to strategically position themselves within the scientific community.

According to Goffman (1973), it is possible to distinguish between "focused" and "unfocused" encounters at conferences. Focused encounters refer to concrete social interactions such as presentations, contributions to discussions, and personal conversations at the margins of an event. In contrast, unfocused encounters are characterized by mere co-presence in the same space (Hettlage, 2007). Considering the differences between conferences held in physical versus virtual environments, it is reasonable to assume that participants will experience both types of encounters, which can be clearly differentiated across these settings.

2.2. *Sustainability of Academic Conferences*

Growing awareness of planetary boundaries (Steffen et al., 2015) led to increasingly questioning the sustainability of academic conferences over the past two decades (e.g., Welch et al., 2010). The concept of

sustainable development is to meet the needs of the present without compromising the ability of future generations to meet their own needs (UN, 1987). The three-pillar model of sustainability conceptualizes sustainability as the balanced integration of ecological, economic, and social goals. These goals are represented by equally high pillars carrying the weight of sustainability as a shared roof (see Fig. 1). This symbolizes that all goals are considered equally important. Alternative illustrations depict the goals as overlapping circles, which emphasizes the possibility of competing priorities and trade-offs at the intersections between ecological, economic, and social objectives (Purvis et al., 2019).

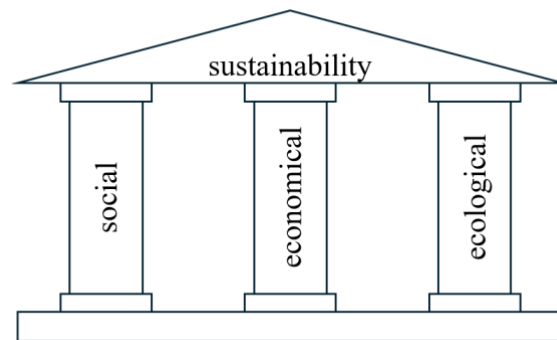


Fig. 1. The three-pillar model of sustainability (Purvis et al., 2019).

On-site conferences offer increased interaction quality and rich informal exchanges. These can foster professional inclusion and community building, thereby supporting social sustainability. They can also stimulate innovation capacity, more equitable knowledge transfer and opportunities in academic labor markets which can improve economic sustainability. Despite these benefits, economic and social demands caused by long-distance travel have to be taken into consideration. This particularly affects researchers with limited financial resources or care responsibilities. Emissions related to mobility increase the carbon footprint and thereby affect the ecological sustainability. Further disadvantages are caused by high travel costs, which restrict socially sustainable and inclusive participation in global academic exchange.

From this perspective, online academic conferences for example via videoconferencing, can offer a promising alternative. Travel-related emissions and costs can be reduced, which benefits ecological and economic sustainability as well as the social component. The reduction of time and cost commitment can enable a broader range of participants from economically challenged environments or people with less resources to attend. However, the inherent technical characteristics limit interaction quality, for instance through reduced visibility of nonverbal signals and kinesthetic restriction. Using such systems can contribute to physical and cognitive exhaustion, often referred to as “Zoom fatigue”, which can be attributed to several intertwined mechanisms. Constant self-viewing can heighten self-consciousness, together with the feeling of being permanently observed increases mental strain. The fixed camera frame can restrict movement, and therefore create a sense of confinement. The continuous effort required to produce and interpret nonverbal signals, process dense streams of social cues and manage turn-taking further adding to cognitive load. This has been associated to have a particularly pronounced effect on women and individuals with certain personality traits (Fauville et al., 2023). These factors show, that videoconferencing environments generate unique psychological and physiological demands, that diminish interaction quality and user well-being (Bailenson, 2021; Bonfert et al., 2022; Fauville et al., 2023). Individuals who are more vulnerable to cognitive overload or who already experience high everyday-stress-levels, are likely to be affected. Therefore, social sustainability is negatively affected in terms of equitable participation and inclusion. Furthermore, this heightened strain reduces participants’ ability to engage fully and meaningfully in conversations. Consequently, it constrains the effectiveness of academic exchange and diminishes the efficient use of communicative and cognitive resources, creating an important consideration for economic sustainability.

Addressing these issues, Social VR technologies represent a promising alternative. They replicate physical spaces, such as conference centers, and enable relatively realistic interaction between participants through avatars (Bainbridge, 2007). By eliminating travel-related ecological and economic costs and facilitating broader access, such environments can promote more socially sustainable participation in academic events.

2.3. Sustainability potentials of Social VR for Academic Conferences

Preliminary theoretical considerations, regarding the potential added value of Social VR technologies and environments for the sustainability of virtual interaction, can be derived from the Theory of Immersive Collaborative Learning (TICOL; Makransky & Petersen, 2023; see Fig. 2), particularly in the context of academic online conferences.

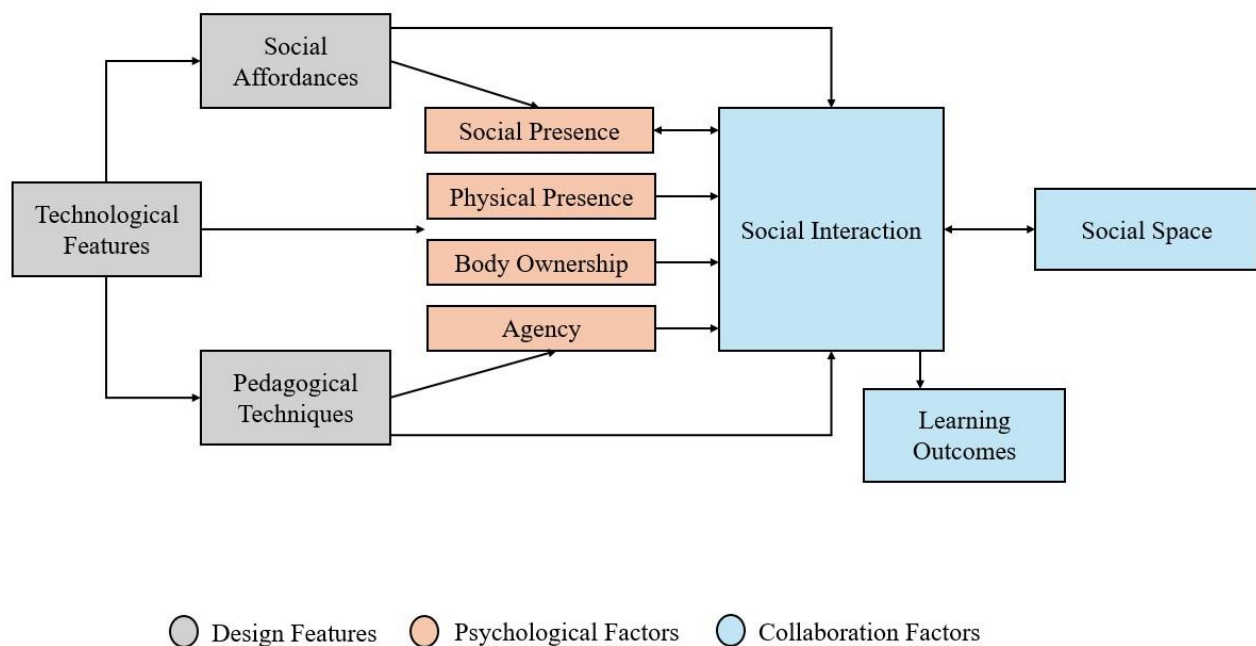


Fig. 2. The Theory of Immersive Collaborative Learning (Makransky & Petersen, 2023).

This framework illustrates the interaction of technological features, social affordances, and didactic methods which shape presence, embodiment, agency, and in consequence the quality of collaborative interaction. Technological features including the level of immersion, such as wide fields of view and spatial audio, create a more natural communication flow. Additionally, representational fidelity can be achieved through avatars displaying consistent gestures or even natural-language responses from intelligent agents. These features enable social affordances, for example avatar-based small group discussions lowering communication barriers, or structured group norms that guide turn-taking in conversation. These affordances are translated into learning design by didactic methods. Examples include role assignment to encourage participation, scripts that prompt elaboration, or collaborative mapping, where participants construct a diagram in shared virtual space.

These interacting mechanisms cultivate social and physical presence, a subjective sense of embodiment, and perceived agency. A high-immersion VR environment, for example with realistic avatars, can allow learners to point at virtual objects and coordinate gestures, resulting in strengthened joint attention and trust. Similarly, when participants swap roles in a design task, they experience greater agency and ownership, while collaborative mapping makes ideas more tangible in a way, that deepens the understanding. Therefore, TICOL shows, how well-designed technological and pedagogical features can generate shared social experiences, supporting competence development as well as socio-emotional engagement.

It can be assumed, that Social VR environments enable a higher quality of socio-spatial interaction than videoconferencing systems, while simultaneously reducing “Zoom fatigue”. These effects are linked to the predominant absence of the two key triggers, hyperdimensional eye contact and visual self-focus (Bailenson, 2021), within Social VR settings. In the context of academic conferences, this interaction quality is a core condition, not only for effective collaborative learning, but also for social sustainability (e.g., inclusive participation, long-term networking), and economic sustainability (e.g., ensuring that investments in Social VR infrastructures pay off through richer, more productive exchanges). As these interaction processes determine, who can meaningfully participate and how durable professional ties become, well-designed Social VR conferences have the potential to contribute directly to more socially and economically sustainable academic exchange.

2.4. Empirical Findings on Sustainability of Academic Conferences in Social VR

In recent years, several case studies have explored the use of Social VR for academic conferences. One of the pilot examples was provided by Welch et al. (2010), who showed that VR poster sessions with around 50 participants were technically feasible and offered flexible interaction structures that are difficult to realize in physical meetings. At the same time, challenges related to poster integration, spatial design and interaction protocols were observed. In a further study, Erickson et al. (2011) analyzed a large-scale event using surveys and interviews. Participants reported positive experiences with networking, multimodal engagement, and random encounters, while also noting technical barriers, onboarding challenges, and reduced nonverbal cues. In a more recent study, Zender and Mulders (2021) found overall positive evaluations among 75 participants, with social presence and immersive experience frequently highlighted alongside discomfort and usability issues. Reduced travel and environmental benefits were mentioned as advantages. A virtual conference with around 50 participants examined by Estien et al. (2021) suggested that immersive formats can function as viable standalone options, offering accessibility, global reach and multimodal engagement that extend beyond both on-site and videoconferencing experiences. Ahn et al. (2021), combining surveys, observations and interviews, similarly reported reduced financial and temporal barriers, broader participation and lower psychological strain, indicating improved accessibility and inclusion. Kirchner and Nordin Forsberg (2021), focusing on a Social VR reception embedded in an online conference, concluded that Social VR enables more organic interaction than videoconferencing, while still facing limitations in nonverbal communication, hardware requirements and usability. Moreira et al. (2023) examined an online conference with survey and observational data. Their findings suggest that embodied presence through avatars, integrated social activities, and persistent discussion channels foster richer engagement, accessibility and inclusion. Compared to videoconferencing, participants reported more meaningful social interaction and the formation of new professional contacts. At the same time, reduced spontaneity, technical hurdles, and multi-platform fatigue pointed to limits in both interaction quality and economic sustainability, as fragmented tool use increased cognitive load and reduced efficiency. These results on academic conferences in Social VR align with findings from Social VR in teaching and extracurricular settings (Merkel-Kiss et al., 2024), which emphasize the technology’s strong potential for fostering social integration despite technical limitations (Merkel-Kiss & Markgraf, 2025).

Overall, existing research implicitly points to the potential of Social VR to contribute to ecological sustainability through reduced travel, economic sustainability through scalable and time-efficient participation, and social sustainability through enhanced accessibility, perceived inclusion, reduced psychological strain and increased social presence. However, it does not establish explicit links to the sustainability dimensions. At the same time, interaction quality, which appears to be a critical factor particularly influencing social and economic sustainability, is typically addressed through isolated aspects such as presence, spontaneity or nonverbal cues, rather than as an integrated construct explicitly related to sustainability outcomes. In addition, direct, systematic comparisons between on-site, videoconferencing and Social VR formats academic conference formats remain rare, and are seldom analytically linked to overall suitability, interaction quality, or sustainability (Hohlfeld et al., 2021). Addressing this gap requires moving beyond isolated, experience-based accounts toward integrated research designs that explicitly

connect interaction quality with social, economic, and ecological evaluations and with participants' concrete preferences across conference formats.

The present study responds to this need by addressing the following research questions:

- RQ 1: Which of the three conference formats, on-site, videoconferencing, or Social Virtual Reality, is preferred by prospective participants of academic conferences?
- RQ 2: How do participants evaluate the overall suitability and interaction quality of academic Social VR conferences, including their perceived advantages and disadvantages, compared to on-site and videoconferencing formats with respect to social, economic, and ecological sustainability?

3. Methodology

3.1. Research Design

A convergent mixed methods design (Cresswell et al., 2023) was employed in this study, combining quantitative data from closed-ended questions with qualitative data from open-ended responses. Both data types were collected simultaneously and analyzed separately, then integrated to provide a more comprehensive understanding of participants' perspectives. This design was chosen to capture both, the measurable patterns, and the nuanced explanations, underlying participants' assessments.

3.2. Data Collecting Tools

The survey consisted of 21 closed-ended items and one open-ended question. The closed items covered task-technology fit, interaction quality, preferred conference format, and demographic variables, while the open question invited participants to elaborate on perceived advantages and disadvantages of Social VR conferences.

Suitability. Participants' perceptions of suitability were assessed using the Task-Technology-Fit Scale (Howard & Rose, 2019). The scale included nine items (e.g., "The technology is appropriate to perform the task(s).") rated on a five-point Likert scale, ranging from strongly disagree to strongly agree.

Interaction quality. Since no standardized measures exist, to assess interaction quality, an eight-item ad-hoc scale was developed specifically for the present study. The item content was derived from a review of relevant literature on communication and social presence in virtual environments (e.g., Han & Bailenson, 2024; Makransky & Petersen, 2023; Saeed et al., 2008; Santoso et al., 2025) and aimed to capture facets such as feedback responsiveness, effectiveness, agency, nonverbal expressiveness, and social connectedness (see Table 1). To ensure content validity, the items were reviewed by three experts in educational psychology and media research, as well as subsequently being refined accordingly. In a pretest, the items were evaluated for clarity and relevance. The items were to be rated on a five-point Likert scale, ranging from strongly disagree to strongly agree.

To assess the construct validity of the eight items, which've been developed to measure perceived interaction quality in Social Virtual Reality (Social VR), an exploratory factor analysis (EFA) was conducted using principal axis factoring. The analysis was based on data from all 40 participants. Sampling adequacy was confirmed by the Kaiser–Meyer–Olkin measure ($KMO = .817$), indicating a meritorious level of suitability for factor analysis. Bartlett's test of sphericity was significant ($\chi^2(28) = 164.36, p < .001$), suggesting that the item correlations were sufficient to justify the use of factor analysis. Based on the Kaiser criterion (eigenvalue > 1), two factors were initially extracted, accounting for 74.8% of the total variance. However, the extraction process did not converge within the default number of iterations (25), indicating instability in the two-factor solution. Examination of the factor matrix revealed that most items were loaded strongly on a single dominant factor, which alone explained for 60.3% of the total variance. This factor captured key aspects of communication and social interaction within the virtual environment, including perceived communicative effectiveness, feedback exchange, and interpersonal engagement. Two items showed moderate cross-loadings on a second, weaker factor, which appeared to reflect participants' subjective comfort during discussions. These were the items "I felt comfortable participating in

discussions” (loading = .597 on Factor 1; .636 on Factor 2) and “I felt comfortable interacting with other participants” (loading = .675 on Factor 1; .447 on Factor 2). While both items still loaded moderately on the main factor, their secondary loadings suggest a possible subdimension related to emotional ease or communicative confidence in the virtual setting. These findings support the internal coherence of the item set and provide preliminary evidence for its construct validity, in the context of academic conferencing in immersive virtual environments.

Table 1.

Items and factor structure of the interaction quality scale.

No.	Item	Facet	Factor 1 Loading	Factor 2 Loading
1	The technology allowed me to show and see reactions in a timely manner.	Responsiveness	.651	
2	Through the use of the 3D environment, I was able to communicate better with presenters and other participants.	Effectiveness	.878	
3	In the 3D environment, I could shape the interaction with others according to my personal needs.	Agency	.819	
4	Through my avatar, I could convey a variety of different signals during communication.	Expressiveness (nonverbal)	.662	
5	The 3D environment allowed me to get to know other participants.	Connectedness (social)	.768	
6	Communication in a 3D environment is an excellent medium for social interaction.	Suitability	.898	
7	I felt comfortable participating in discussions.	Comfort (verbal)	.595	.636
8	I felt comfortable interacting with other participants.	Comfort (interpersonal)	.675	.447

Preferred Format. Participants’ preferred format for attending academic conferences was assessed through the question: “If academic conferences were offered in person, in video conferencing software, and in the 3D virtual environment, what would you choose?”. The response options were “3D environment”, “video conferencing software” and “face-to-face event”.

Advantages and disadvantages of Social VR. An open-ended item (“What advantages and disadvantages do you see in using a virtual 3D environment?”) invited participants to elaborate on the perceived advantages and disadvantages of using a Social VR environment.

Sociodemographics. Finally, several sociodemographic variables were collected, including age, gender, highest educational qualification, and current professional activity. For respondents working in academia, additional information was gathered, regarding their specific role (e.g., professor, research associate).

With the exception of the open-ended questions, all items were mandatory. Items were displayed individually or in grouped scales across separate pages.

3.3. Sampling

A total of 32 participants took part in the survey following the academic conference, corresponding to a response rate of 50.8%. Of these, 56.3% identified as female, 40.6% as male, and 3.1% as non-binary. The average age was 48.6 years (SD = 10.5), ranging from 23 to 63 years. Regarding educational background, the majority held a doctoral or postdoctoral qualification (n = 18; 56.3%) or a degree such as diploma, state examination, Magister, or Master’s degree (n = 12; 37.5%). One participant each reported a (specialized) secondary school diploma or a Bachelor’s degree (3.1% each) as their highest qualification. Most participants (n = 19) reported working in academia, while twelve respondents (alternatively or additionally) reported employment in industry or being enrolled in education or training. Among the academic professionals, 14 were professors (43.8%), four were research associates (12.5%), and one held another academic position. The professors and research associates represented a wide range of academic disciplines.

The majority ($n = 8$) reported working in the field of educational and social sciences, including digital education and inclusion. Five participants had backgrounds in business, management, or communication-related disciplines. Two participants were active in technical or media informatics fields, and one person worked in an interdisciplinary area combining ethics, sustainability, and sociology. Three responses could not be clearly categorized due to missing or ambiguous entries.

3.4. Data Analysis

The analysis focused on participants' assessments of their preferred conference format and their perceptions of the overall suitability, strengths, and weaknesses of Social VR for academic conferencing with regard to social, economic, and ecological sustainability. Descriptive statistics, including means, standard deviations, frequencies, and percentages, were calculated for all closed-ended items. Open-ended responses were examined using qualitative content analysis (Kuckartz, 2022). This method enables the systematic and rule-based categorization of textual data according to thematic aspects. In the present study, main categories were derived deductively based on the three-pillar model of sustainability, while subcategories were developed inductively from the most frequently mentioned aspects in the data, following the logic of content-structuring analysis. Each category represents a distinct thematic dimension relevant to the research questions, in particular RQ 3, and is illustrated in the coding scheme (see Tab. 2).

Table 2.

Coding framework used for analyzing advantages and disadvantages of Social VR conferences.

Main category	Subcategory	Description	Example quotation
Economic sustainability	Time efficiency	Saving time due to the elimination of travel and reduced scheduling effort	"Travel time is saved." (ID 31)
	Cost efficiency	Saving money by avoiding travel and accommodation and enabling participation without additional financial burden	"Participation is cost-effective and less time-consuming." (ID 6)
	Motivation and user engagement	Perceived enjoyment, fun and engaging character of conferences that can increase motivation to participate and remain engaged	„Fun factor, different form of online communication, something different.“ (ID 23)
	Didactic and creative potential	Use of simulations, playful scenarios and flexible environments that increase learning effectiveness and scalability while enabling more efficient use of personnel, time and material resources	„Immersive experiences through immersion in completely new worlds. This can be useful both playfully, such as escape rooms, and in training or simulation of real scenarios.“ (ID 14)
	Hardware costs	Financial and resource-related implications of acquiring, maintaining and updating the hardware and technical infrastructure required for Social VR conferences	"Disadvantages: Technical requirements – not all users have the necessary hardware." (ID 14)
Social sustainability	Accessibility	Reduced participation barriers through flexible access (any time and any place) and low entry thresholds	"Accessibility and flexibility, as they can be accessed at any time and from almost any location. This enables broader use and can be especially beneficial for distance learning or online events." (ID 14)

	Equality	Perceptions of equal footing and reduced hierarchy between participants of different status groups	“More of an equal footing for all participants, all are using avatars, no advantages for home presenters.” (ID 4)
	Social presence	Feeling of presence and realistic conference experience	“Overall, the 3D environment offers an excellent alternative to on-site events.” (ID 6)
	Social proximity	Features of the Social VR environment that enable spontaneous encounters, informal conversations and a feeling of social closeness or networking among participants	“Immersion furthermore enables me to feel closer to other participants – I can approach others and start conversations with them even unplanned.” (ID 35)
	Social interaction constraints	Limitations of informal exchange and emotional connection in Social VR, including fewer spontaneous encounters during breaks and restricted nonverbal expressiveness of avatars	“Disadvantage: lack of personal exchange after the event, café/bar socializing is missing.” (ID 9)
	Barriers to accessibility	Exclusion or disadvantage of participants who lack adequate hardware, bandwidth or digital skills to use Social VR conferences	“Disadvantages: Technical requirements – not all users have the necessary hardware and lack digital skills.” (ID 14)
Ecological sustainability	Reduced carbon footprint	Environmental benefits through avoided travel and reduced use of physical conference infrastructure	“Advantages lie absolutely in the elimination of travel time and costs (commute, possibly accommodation, etc.).” (ID 39)

3.5. Validity and Reliability

To ensure the validity and reliability of the study, both the quantitative and qualitative components were considered separately and in their integration. For the quantitative part, internal consistency was assessed using Cronbach's alpha. The Task-Technology Fit scale yielded an excellent reliability coefficient ($\alpha = .98$), indicating a very high level of internal consistency. Similarly, despite the relatively small sample size ($N = 32$), internal consistency of the item set developed to assess perceived interaction quality was good ($\alpha = .90$), suggesting a reliable measurement of the construct. Content validity was supported through theoretical grounding and expert review during the development of the questionnaire.

For the qualitative part, interpretive validity was addressed by combining frequency-based analysis with in-depth interpretation of the coded content. To support transparency and reliability, coding decisions were discussed within the research team and continuously reflected throughout the process. The integration of both data types followed a convergent design, allowing for methodological triangulation. Converging results across the quantitative and qualitative strands support the robustness of the findings, while divergent aspects were interpreted as complementary and served to enrich the overall understanding of participants' perspectives.

3.6. Research Procedures

An academic conference was planned and implemented in a Social VR setting to empirically explore the guiding research questions. Participants were recruited through an online announcement and targeted dissemination within existing networks. The conference focused on digitization in higher education and the use of Social VR in teaching and learning. The goal was to bring together researchers and practitioners from different disciplines to discuss ways, in which digital technologies are reshaping academic work and higher education. The program was organized into several thematic tracks addressing topics such as digital

learning and teaching scenarios (e.g., innovative online and hybrid course designs and self-directed learning formats), artificial intelligence (AI) and AI literacy in higher education (e.g., fostering AI competencies among students and staff and addressing algorithmic bias), Social VR and immersive learning environments (e.g., VR-supported teaching concepts, virtual laboratories, and conference formats), digital assessment and learning analytics (e.g., data-informed feedback and competence-oriented e-assessment) and the ethical, social, and sustainability-related implications of digital technologies (e.g., data protection, platform economies, and the role of digitalization in sustainable higher education). Further contributions explored organizational and pedagogical transformation processes in digitally mediated education, such as the changing roles of teachers and students, new participation formats and institutional strategies for implementing digital innovation. Most participants had an academic background (see section 3.3: Sampling) with previous experience in online conferences but limited prior exposure to Social VR environments. To ensure a smooth process, technical briefings were offered in advance of the event. In addition, continuous technical support was provided during the conference, within the virtual environment as well as via a parallel videoconference room, to address potential technical issues.

The Social VR platform TriCAT Spaces® was selected as the application environment because of its realistic design and its low-threshold usability via mouse and keyboard (Rinn et al., 2023). In addition, the platform imposes relatively low hardware requirements, as it does not necessitate the use of VR headsets or high-performance computers. The virtual conference environment was designed to resemble a realistic academic environment. Spatial audio and a balanced combination of virtual indoor and outdoor areas supported this sense of realism and created a relaxed atmosphere (Khosrawi-Rad et al., 2023). Participants were able to design individualized avatars, which could be customized to resemble their own appearance using portrait photographs, thereby strengthening identification with the virtual self (Rinn et al., 2023). In addition, spatial audio and color-coded rooms operationalized technological features that support joint attention and orientation, whereas customizable avatars and co design of objects during the social evening targeted social affordances and a sense of ownership, as described in TICOL. Fig. 3 displays selected scenes from the academic conference held in the Social VR environment, illustrating key aspects of the virtual setting and user interaction.



Fig. 3. Selected views of different spaces and interaction settings during the academic Social VR conference.

The conference spaces consisted of the main auditorium and several training environments and were designed with distinct color schemes (orange, blue, green, pink) to facilitate participant orientation. Decorative elements such as plants and color-coordinated three-dimensional objects were added to create an engaging environment. Seating areas were deliberately arranged to encourage informal conversations alongside formal conference activities.

The conference took place within two consecutive days. At the start of each day, keynote lectures were held in the main auditorium. On the first day, participants could then choose from four parallel activities designed to foster social interaction: a virtual Easter egg hunt, an escape room on the history of virtual worlds, a showcase of an orientation workshop at AKAD University and a poster session. The day concluded with a social evening event in which participants could further explore the virtual environment, engage in informal conversations, and experiment with the scene editor to co-design elements of the virtual world. On the second day, the program included three thematic sessions as well as a workshop session. Participants were able to switch between rooms within the virtual world using a context menu.

The social activities (e.g., virtual Easter egg hunt, escape room, collaborative poster session) were intentionally designed as collaborative tasks that required joint problem solving, navigation and coordinated actions in shared virtual space. In line with TICOL, these activities aimed to leverage technological features (immersion, spatial audio, shared objects) and social affordances (small-group collaboration, role distribution) to foster social presence, embodiment and agency during interaction. For instance, the escape room prompted participants to discuss clues and coordinate actions, while the egg hunt and evening reception were designed to support spontaneous encounters and informal networking. Following the conference, participants were invited to complete the structured online survey (see Section 3.2: Data Collecting Tools). The link to the questionnaire was distributed via email immediately after the event.

3.7. Findings and Discussions

The empirical findings are presented in three parts. First, participants' quantitative evaluations of the suitability of Social VR for academic conferences (i.e., task-technology fit) and their perceptions of interaction quality are displayed and discussed. Second, participants' preferred conference formats are reported, followed by their assessments of the advantages and disadvantages of Social VR compared to on-site and videoconferencing formats. Third, the findings are integrated along the three sustainability dimensions (economic, social, and ecological sustainability) using quantitative measures and qualitative free-text comments.

Suitability. Respondents reported a generally high task-technology fit between Social VR technology and the requirements of active conference participation ($M = 4.38$; $SD = 0.75$). Only three participants perceived the technology as unsuitable (6.3%) or moderately suitable (3.1%), while ten respondents (31.3%) rated it as suitable and 19 (59.4%) as very suitable. The high ratings for task-technology fit provide empirical support that Social VR can serve as a suitable environment for structured academic exchange. Importantly, our study adds to the evidence base by using a validated scale rather than self-constructed items, thereby strengthening the reliability of this finding.

Interaction quality. In terms of interaction quality, the highest mean rating was given to the statement that the technology enabled timely reactions and feedback ($M = 4.31$; $SD = 0.78$). Moderate to high agreement was also expressed regarding the statements: "Through the 3D environment, I can communicate more effectively with presenters and other participants" ($M = 3.31$; $SD = 1.23$), "The 3D environment allows me to shape my interactions with others according to my personal needs" ($M = 3.63$; $SD = 1.10$), and "Through my avatar, I can convey a variety of signals during communication" ($M = 3.38$; $SD = 1.07$). Similar ratings were obtained for "The 3D environment allowed me to meet other participants" ($M = 3.66$; $SD = 1.21$) and "Communication in a 3D environment is an excellent medium for social interaction" ($M = 3.44$; $SD = 1.19$). In contrast, particularly high levels of agreement were reported for feeling comfortable participating in discussions ($M = 4.09$; $SD = 1.03$) and interacting with other participants ($M = 4.22$; $SD = 0.91$). These results are illustrated in Fig. 4.

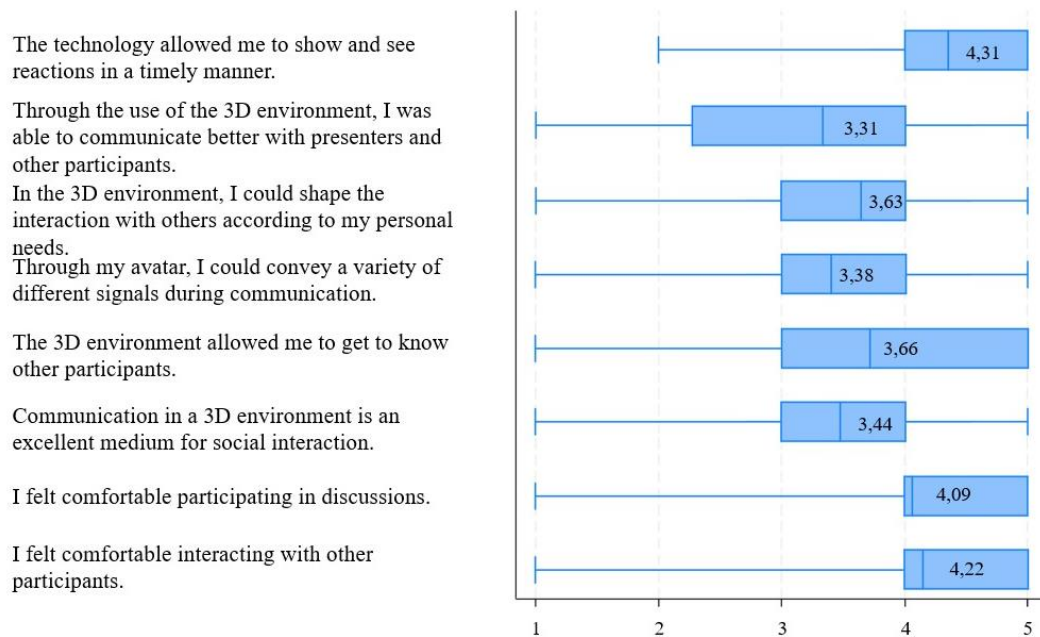


Fig. 4. Results for the eight survey items assessing perceived interaction quality in Social VR conferences.

Our results confirm that Social VR supports meaningful interaction, particularly in terms of responsiveness and feedback, while also revealing gaps in the richness of nonverbal signals. By applying an interaction quality scale developed through theory-informed item construction, expert pretesting, and exploratory factor analysis, this study advances the field beyond prior research that relied mainly on qualitative impressions or ad-hoc measures.

Preferred Format. Nearly half of the respondents ($n = 14$; 43.8%) indicated a preference for on-site conferences, while 13 participants (40.6%) preferred Social VR environments, and only five participants (15.6%) chose videoconferencing systems (see Fig. 5). These findings underline that while face-to-face meetings remain the gold standard, Social VR is emerging as a serious alternative that goes beyond videoconferencing. This trend suggests that the format is gradually moving from experimental trials toward becoming a mainstream option in academic conferencing. The preference distribution is reflected in the arguments that respondents provided regarding the perceived advantages and disadvantages of the different conference formats.

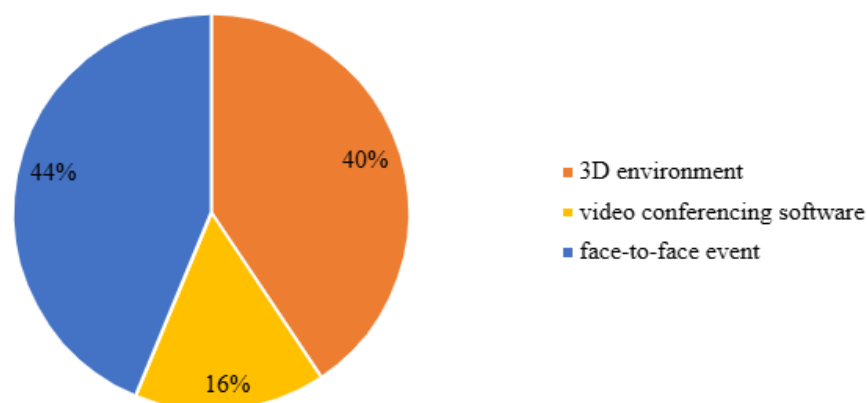


Fig. 5. Reported preferences of participants regarding academic conference formats.

Advantages of Social VR. The most frequently cited advantage concerned time and cost efficiency and was mentioned 12 times. Participants emphasized that Social VR conferences save travel time and reduce financial costs for travel and accommodation, thereby enabling more flexible participation even alongside other commitments. Beyond these economic benefits, several respondents highlighted the motivating and enjoyable character of the environment, describing Social VR as a “fun” and “different” way of communicating, that can increase engagement and willingness to participate repeatedly. In addition, comments pointed to the didactic and creative potential of immersive simulations and customizable scenarios, which were seen as offering efficient, reusable learning environments for training and problem solving in a safe and controlled setting.

From a social sustainability perspective, respondents particularly emphasized feelings of equality, social presence, and inclusive participation. Several participants reported that interactions in Social VR felt more “on equal footing” because everyone appears as an avatar, which makes hierarchical differences less visible and reduces inhibitions for students and early-career researchers when approaching more senior academics. At the same time, Social VR was perceived as providing a stronger conference atmosphere and social presence than conventional videoconferencing, for example through spatialized rooms, movement, and side conversations that foster a more realistic conference feeling. These accounts suggest that Social VR can actively contribute to socially sustainable conference participation by lowering social barriers and enabling new forms of interaction.

Disadvantages of Social VR. A key disadvantage was the limitation of social interaction compared to face-to-face communication, which was mentioned eleven times. Respondents noted that, due to the limited nonverbal cues available through avatars, interactions can feel more anonymous and impersonal, making it harder to read others’ emotions and intentions and thereby reducing the sense of social presence. Several participants also pointed out, that opportunities for informal exchange, during breaks or immediately after academic sessions, are less available or less spontaneous in Social VR, with coffee-break conversations, bar encounters, and social evening events being perceived as clearly more satisfying in on-site settings. These issues are closely linked to lower ratings for avatar-based nonverbal signaling.

Another recurrent theme concerned accessibility and barriers to accessibility. Whereas Social VR can reduce participation barriers by allowing people to join from different locations and life situations, technical requirements such as necessary hardware and digital skills were described as significant hurdles for some participants and were seen as excluding those without sufficient equipment or experience. These aspects indicate that the social sustainability of Social VR conferences depends strongly on supportive institutional frameworks and user-centered design. Finally, participants mentioned that initial and ongoing investments in hardware and infrastructure can limit the economic advantages for some users or institutions.

Taken together, these qualitative results show that Social VR offers substantial economic and social sustainability benefits, but that limitations in informal interaction, nonverbal expressiveness and access remain important challenges. To provide a more systematic overview of how these qualitative findings relate to the quantitative measures, the following section integrates both strands of data along the three sustainability dimensions.

Mixed Methods Integration. To synthesize the quantitative survey results and the qualitative free-text comments, the findings were mapped onto the three sustainability dimensions, drawing on the main categories of the coding framework. Table 3 summarizes the relevant constructs, the corresponding quantitative findings, illustrative qualitative quotations, and an integrated interpretation for each dimension.

Table 3.

Integrated quantitative and qualitative findings along sustainability dimensions.

Main category	Construct	Quantitative findings	Qualitative finding	Integrated interpretation
Economic sustainability	Task–technology fit for active participation	High overall suitability of Social VR for conference participation ($M = 4.38$; $SD = 0.75$).	Participants emphasized that Social VR fits well with their work routines by saving time and costs compared to on-site events.	Convergence: High task–technology fit ratings are mirrored by repeated mentions of time and cost savings, underscoring strong economic benefits of Social VR conferences
	Time and cost efficiency	Not directly measured by a separate item; reflected in generally high suitability ratings.	Respondents highlighted reduced travel effort, flexible participation, and lower travel and accommodation costs as central advantages.	Exploratory: Qualitative findings indicate clear time and cost efficiency benefits of Social VR, which are consistent with the unspecific quantitative suitability ratings.
	Motivation and user engagement	Not directly measured by a separate item; reflected in generally high suitability ratings.	Social VR was described as enjoyable, different, and engaging, making participation more attractive than standard videoconferencing.	Complementarity: Quantitative suitability scores indicate willingness to use Social VR; qualitative data add that enjoyment and novelty foster motivation and ongoing engagement, supporting economic sustainability through more productive use of conference resources.
	Didactic and creative potential	Not directly captured by a separate item; reflected indirectly in high suitability.	Participants perceived Social VR as a versatile, reusable environment for learning, training, and simulations with high creative potential.	Complementarity: Quantitative data confirm that Social VR is suitable for conferences; qualitative responses expand this by highlighting didactic and creative affordances that can increase scalability and efficiency, contributing to economic sustainability.
	Hardware costs	Not directly measured by a separate item; reflected in generally high suitability ratings.	Some respondents reported missing hardware and additional effort due to technical requirements and digital skills gaps.	Divergence with qualification: While overall suitability is rated high, qualitative data reveal hardware and skill requirements that imply additional investments and can partially offset economic gains.

Social sustainability	Social interaction	Moderate agreement to the corresponding items (means in the mid-3 range) with relatively large variability.	Social VR was experienced as socially richer than videoconferencing, with more conference feeling and additional spaces for interaction.	Complementary: Quantitative data show that social interaction is generally rated as good but not uniformly excellent; qualitative data specify that Social VR affords a stronger conference feeling and additional conversational spaces than videoconferencing.
	Feeling comfortable participating in discussing and interacting with others	High comfort ratings ($M \approx 4.1-4.2$).	Respondents reported reduced hierarchies, lower inhibitions and a strong sense of safety when contributing and interacting.	Convergence: High comfort ratings align with perceptions of lowered hierarchies and reduced inhibitions, indicating socially inclusive interaction and supporting the subcategories Equality and Accessibility.
	Effectiveness of communication	Moderate agreement that the 3D environment supports effective communication ($M \approx 3.3-3.6$).	Communication in Social VR was perceived as generally effective, especially due to increased participation and fairer turn-taking.	Convergence with nuance: Participants perceive communication as generally effective, particularly due to increased participation and perceived equality, but not yet superior to on-site interaction in all respects.
	Social presence and perceived conference atmosphere	Items on presence and technology quality for social interaction reached moderate to good values.	Social VR was perceived as a convincing conference setting that generates a stronger sense of presence and atmosphere than videoconferencing.	Convergence: Survey and free-text agree that Social VR produces a stronger conference atmosphere and social presence than videoconferencing, although still not fully equivalent to on-site events.
	Nonverbal signaling via avatars	Lower ratings compared to other interaction items (around the mid-scale range).	Participants experienced limitations in facial expressions, gestures and subtle social cues as a central weakness of avatar-mediated interaction.	Strong convergence: Both data strands show that limited nonverbal expressiveness is a key weakness, constraining social presence and fine-grained interpersonal perception
	Opportunities to meet others and for informal networking	Mid-range ratings for “meeting other participants” ($M=3.44$)	Informal encounters, especially coffee-break and evening conversations, were perceived as insufficient or less spontaneous than at on-site conferences.	Complementary: Quantitative findings signal room for improvement in networking; qualitative data specify missing informal encounters and coffee-break talk as central deficits within social interaction constraints.

	Accessibility and barriers to accessibility	No dedicated quantitative item, but related to suitability and participation comfort.	Flexible, location-independent access was seen as lowering participation barriers, while hardware and skill requirements were experienced as excluding some groups.	Complementarity: While Social VR can reduce participation barriers through flexible, location-independent access, technical and skill requirements create barriers to accessibility, so that social sustainability depends on support and inclusive design.
Ecological sustainability	Reduced travel and resource use	High suitability and positive ratings for remote participation indicate substitution potential for some on-site events.	Respondents emphasized avoided commuting and overnight stays and a lower logistical burden as important advantages of Social VR.	Convergence: If Social VR is accepted as a suitable conference format, reduced travel and venue use can translate into a lower environmental footprint, even if participants primarily frame this in terms of time and cost savings.

Economic sustainability. Although task-technology fit does not directly capture economic sustainability, the high ratings observed in the quantitative data may reflect underlying efficiency benefits. This interpretation is supported by the the qualitative accounts, in which saving travel time, reducing organizational effort, and avoiding travel and accommodation costs were among the most frequently mentioned advantages. Participants repeatedly emphasized that they could attend more flexibly, integrate the event into their everyday schedules, and reduce financial burdens, suggesting that Social VR can yield clear economic benefits when it replaces or complements on-site events in suitable contexts. In addition, participants' descriptions of enjoyment, novelty, and repeated use point to aspects, that are not directly captured by the interaction quality scale but are visible in both preference data and free-text responses. Social VR was portrayed as a fun, different, and engaging way of communicating, with some respondents explicitly highlighting the playful character of the environment as something that makes participation more attractive and encourages them to return. Such motivational effects can indirectly enhance economic sustainability by stabilizing participation rates, reducing drop-out and improving the return on investments in virtual conference infrastructures. Beyond this, respondents also stressed the didactic and creative potential of Social VR. Immersive simulations and customizable environments were seen as efficient, reusable learning and training settings that can be deployed multiple times and across different events. In this way, time and cost efficiency, motivational engagement, and didactic scalability reinforce each other rather than constituting separate, unrelated effects. At the same time, comments on hardware requirements and technical infrastructure indicate that economic gains are partly offset by the need for adequate devices and connectivity. While many participants rated the platform as technically well implemented and exceeding their expectations, others reported that not all users have the necessary hardware or digital skills and that some functions could be simplified to reduce cognitive load. This suggests that economic sustainability benefits depend on sufficient infrastructure, technical support, and thoughtful platform design. Without these enabling conditions, the same technical complexity that allows for rich, scalable scenarios can increase effort and limit perceived suitability.

Social sustainability. The results for social sustainability reveal a nuanced pattern of strengths and limitations in how participants experienced interaction in Social VR. Quantitatively, moderate but positive ratings on the perceived suitability of the 3D environment for social interaction and on opportunities to meet other participants indicate that Social VR is generally perceived as a good, though not flawless, medium for academic exchange. Qualitative statements complement this picture by stressing that the Social VR environment provides a stronger conference atmosphere and additional conversational spaces compared

to videoconferencing. Respondents highlighted that spatially structured rooms, movement, and multimodal cues created a more convincing conference feeling and allowed for side conversations outside formal sessions, illustrating how technological affordances translate into socially meaningful experiences. Social presence and a sense of being on equal footing emerged as central social benefits. Participants described Social VR as an excellent alternative to on-site events and emphasized that interactions felt more balanced because everyone appeared as an avatar and visible status markers (such as clothing or physical staging) were less prominent. This perceived equality aligns with the high comfort ratings for participating in discussions and interacting with others and with reports of reduced inhibitions when approaching more senior academics. Some respondents also noted that immersion made it easier to approach others and start unplanned conversations, pointing to spontaneous encounters and feelings of social closeness that are difficult to achieve in conventional videoconferences. Taken together, these results suggest that avatar-based representation, spatial design, and immersion jointly foster a more inclusive and approachable interaction climate. At the same time, several limitations became apparent. Participants described constraints on informal interaction, reduced richness of nonverbal signaling via avatars, and fewer opportunities for spontaneous encounters, especially during breaks and evening events. Lower ratings for avatar-based nonverbal cues reflected experiences of communication as more impersonal and made it harder to read others' emotions and intentions, while mid-range ratings for opportunities to meet other participants resonated with complaints about missing coffee-break conversations and bar socializing. In addition, the findings show an ambivalent picture regarding accessibility. Flexible, location-independent access was seen as enabling broader participation and supporting distance learning or online events, but technical requirements and skill demands were simultaneously experienced as excluding some user groups. Overall, Social VR thus appears socially sustainable in some respects, particularly equality, presence, and comfort, while still facing challenges regarding informal networking, nonverbal communication and inclusive access. The social gains and deficits are structurally linked. The same avatar-based abstraction that lowers hierarchical barriers also attenuates fine-grained nonverbal cues, and the same spatial flexibility that enables remote access does not automatically reproduce the micro-rituals of on-site coffee breaks.

Ecological sustainability. Ecological sustainability is mainly reflected in avoided travel and the associated reduction in resource consumption. Although the survey did not include specific ecological items, this dimension can be inferred from high suitability ratings and positive evaluations of remote participation. If Social VR is perceived as a functionally adequate conference environment, it can realistically substitute at least some on-site events and thereby reduce emissions and the use of physical conference infrastructure. Qualitative statements highlight these benefits explicitly by emphasizing the elimination of commuting and overnight stays and the general advantage of not having to travel, showing how ecological benefits are often cognitively framed through time and cost savings and illustrating the close coupling between ecological and economic sustainability perceptions. At the same time, participants' comments on sustainability perception and trade-offs indicate that ecological benefits are frequently framed as a secondary effect rather than a primary decision criterion. Some respondents described sustainability aspects as a "nice-to-have", while also pointing to technical, social, and health-related challenges that should be considered when using Social VR environments more extensively. Taken together, the integrated findings suggest that Social VR can contribute to ecological sustainability by reducing travel and physical infrastructure use, but that these advantages will only materialize if the format is accepted as a viable alternative in terms of economic and social sustainability. This interdependence between dimensions implies that interventions aiming to foreground ecological arguments (for example, through carbon accounting or explicit institutional policies) may be most effective when combined with measures that safeguard perceived interaction quality and social inclusion.

Overall, the findings suggest that Social VR can provide an effective and engaging environment for academic conferences. While it offers advantages in terms of accessibility, equality, and social presence, limitations remain with respect to nonverbal communication, informal social encounters, and access barriers for some user groups. These aspects, and their implications for the sustainability–quality trade-off, are discussed further in the following section.

4. Conclusion and Suggestions

The conducted study extends previous research by employing a theoretically grounded and systematic approach to exploring the advantages and disadvantages of Social VR conferences compared to on-site and videoconference formats. It explicitly links participants' format preferences and evaluations of overall suitability and interaction quality to the sustainability dimensions according to the three-pillar model of sustainability.

Regarding interaction quality, which appears to be a critical factor particularly influencing social and economic sustainability, participants' evaluations of core features were largely positive. High ratings for timely reactions and feedback, together with strong comfort in participating in discussions and interacting with others, suggest that Social VR can provide an effective and engaging interaction environment. This resonates with TICOL's assumption that immersion, embodiment, and social affordances can foster shared attention, trust, and collaborative agency when appropriately designed (Makransky & Petersen, 2023). At the same time, the variety of available nonverbal communication signals was perceived as limited, and more intensive social interactions, such as one-on-one conversations or getting to know other individuals, were evaluated positively but with restrictions concerning their depth and spontaneity. A particularly strong result was the high level of comfort participants reported during discussions and other interactions, which may be explained by the relative anonymity afforded by avatars, the perceived safety of the environment and the reduction of self-monitoring due to the absence of webcams, which is in line with prior findings on reduced "Zoom fatigue" in immersive settings (Bailenson, 2021; Bonfert et al., 2023). Consistent with earlier pilot studies (Kirchner & Nordin Forsberg, 2021; Zender & Mulders, 2021), the perceived quality of interaction was positively influenced by the unique conference atmosphere and heightened sense of social presence that Social VR fostered. Participants described the 3D environment as an excellent alternative to on-site events, with spatially structured rooms, avatar movement and multimodal cues creating a more convincing conference feeling than videoconferencing alone. These aspects map directly onto TICOL's emphasis on how immersive technological features and didactic orchestration produce social and physical presence, embodiment and perceived agency. At the same time, informal encounters were evaluated as more limited than in face-to-face settings, confirming that unfocused encounters and serendipitous networking remain challenging to reproduce virtually (Hauss, 2019; Hettlage, 2007).

Consequently, from a sustainability perspective, the results show that Social VR contributes most clearly to economic and social sustainability. Time and cost efficiency, high task–technology fit and perceived suitability for active participation indicate that Social VR can reduce resource demands while supporting productive scholarly exchange. At the same time, participants highlighted increased accessibility and perceived equality, particularly through remote participation and avatar-based interaction, which align with social sustainability dimensions such as inclusion, participation and social connectedness (Holden, 2012; Wolsko et al., 2016). In contrast, ecological sustainability, while clearly inherent to the format, played only a minor explicit role for respondents. Travel reduction and lower resource use were recognized, but primarily framed as side effects of time and cost savings rather than as primary decision criteria, echoing earlier work that treats environmental benefits as secondary to convenience and experience (Leochico et al., 2021). Table 3 summarizes how these patterns emerge across the different interaction and suitability constructs.

From a comparative perspective, the findings help to reframe the assumed sustainability–quality trade-off in academic conferencing. On-site conferences remain the benchmark for rich, spontaneous social interaction and deep informal networking, yet they are ecologically costly and resource-intensive (Burtscher et al., 2020; Klöwer et al., 2020; Topp et al., 2024). Videoconferencing, in contrast, offers substantial ecological and economic advantages but suffers from limited social presence, reduced spontaneity and "Zoom fatigue", with negative consequences for both social and economic sustainability (Bailenson, 2021; Bonfert et al., 2023; Fauville et al., 2023). Against this backdrop, the present study suggests that Social VR represents a promising intermediate option. It substantially reduces travel-related emissions and time costs, while affording a stronger sense of presence, equality and engagement than videoconferencing, even though it does not fully replicate the informal social richness of face-to-face

meetings. Rather than confirming a strict opposition between high interaction quality and sustainability, the results indicate that well-designed Social VR formats can partially decouple this tension by combining ecological and economic benefits with socially acceptable, and in some respects enhanced, interaction quality. To summarize these relationships in a more condensed form, Table 4 provides a comparative overview of on-site, videoconference and Social VR formats with regard to core facets of interaction quality as well as economic, ecological and social sustainability.

Table 4.

Comparison of central aspects of conference formats.

	On-site	Videoconference	Social VR
Interaction quality: verbal	High	High	High
Interaction quality: nonverbal	High	Low	Medium
Interaction quality: informal	High	Low	Medium
Sustainability: Economical	High	High	High
Sustainability: Ecological	Low	High	High
Sustainability: Social	Medium	Medium	High

At the same time, the study confirms technological and social limitations that echo previous research. A recurring critique concerned the limited expressive possibilities afforded by avatars compared to face-to-face communication (Kirchner & Nordin Forsberg, 2021; Merkel-Kiss et al., 2024; Zender & Mulders, 2021). Participants reported difficulties in reading facial expressions, gestures, and subtle social cues, which constrained social presence and fine-grained interpersonal perception. Ongoing technological advancements may alleviate this limitation by enabling more realistic avatars based on photographs, facial tracking, and gaze-tracking (Li et al., 2024), thereby improving recognizability and social orientation in virtual spaces. However, the findings also suggest that purely technical enhancements will not be sufficient. To foster informal interaction and networking, targeted measures in areas such as didactics and organizational design are required, drawing on models like the Framework for Implementation of Virtual Reality in Formal Education (Fischer et al., 2021).

A key added value of this study lies in its methodological rigor. Unlike earlier work that often relied on self-constructed measures, validated scales were employed to assess both task–technology fit and interaction quality. This not only provides more reliable evidence but also fills a significant research gap, as interaction quality in Social VR conferences has been only rarely systematically investigated. By integrating validated, theory-informed measures with qualitative data, the study advances a more robust understanding of the socio-technical affordances and limitations of Social VR conferences across social, economic, and ecological sustainability dimensions.

4.1 Practical implications

The results yield several practical implications for the design and use of Social VR in academic conferencing. First, Social VR appears particularly suitable for events where structured scholarly exchange, inclusive participation, and reduced travel are prioritized, while highly relationship-building formats may still benefit from on-site components. Organizers of academic conferences need to weigh priorities such as ecological sustainability, inclusivity, cost-efficiency, and opportunities for informal exchange when selecting appropriate formats. While Social VR may be particularly well suited for sessions focused on collaborative work, knowledge sharing, or teaching, on-site formats remain advantageous for fostering interpersonal relationships and spontaneous networking.

Second, the findings suggest that interaction quality in Social VR is not only a property of the platform, but also of conference choreography and didactic design, in line with TICOL. To address limitations in informal encounters and support social sustainability, future Social VR conferences should integrate targeted measures to promote informal interaction, such as extended breaks with explicit social goals, structured small-group rotations, or virtual team-building activities that are explicitly linked to collaboration and trust-building (e.g., role-based tasks or collaborative mapping in shared virtual spaces; Kirchner & Nordin Forsberg, 2021; Makransky & Petersen, 2023). Techniques such as the “postcard method” (Knoll, 1995)

can be adapted to Social VR by having participants co-create and exchange short reflective artefacts in shared virtual spaces, thereby concretely operationalizing TICOL's emphasis on shared artefact construction and elaboration.

Third, institutions aiming to use Social VR at scale should consider the economic and social implications of technical access. Shared hardware pools, clear onboarding procedures, and user-centered interface design can mitigate access barriers and usability issues that otherwise temper economic and social sustainability gains. This is particularly relevant in light of empirical evidence linking technical hurdles and fragmented tool use to increased cognitive load and reduced efficiency (Bonfert et al., 2023; Fauville et al., 2023).

4.2 Limitations and future research

Several limitations of the present study should be acknowledged. First, the findings are based on a single conference scenario in a specific institutional and thematic context, and the sample size was relatively small ($N = 32$). Second, only one Social VR platform (TriCAT Spaces®) and conference design were examined. Interaction quality and sustainability perceptions may differ for other tools, devices or event choreographies. Third, data on social interaction and sustainability perceptions were collected exclusively from participants' self-reports shortly after the event, without long-term follow-up or observational triangulation.

A fourth potential limitation concerns the measurement of interaction quality, as the applied scale was specifically constructed for this study rather than adopted from existing instruments. However, the scale should be understood as a theory-informed but exploratory operationalization. Even though the sample size was limited, the internal consistency of the interaction quality scale was high, indicating good reliability. The items were theory-informed (drawing on TICOL and prior work on presence and interaction quality), pilot-tested for clarity and face validity, and an exploratory factor analysis revealed a coherent unidimensional structure. The instrument is not presented as a fully validated scale, but rather as an initial operationalization of the construct for the purposes of this study. In this sense, the mixed-methods approach does not rest on a newly developed measurement tool, but on the combined use of a reliable, theory-based scale and qualitative data to explore the same underlying constructs.

Future research should replicate and extend these findings across multiple conferences, disciplinary fields and technical setups, ideally using experimental or quasi-experimental designs that allow for direct comparisons between on-site, videoconferencing, and different Social VR platforms (Hohlfeld et al., 2021; Moreira et al., 2023). In the context of recurring events such as future editions of the conference examined in this study, longitudinal and cross-cohort designs would make it possible to track whether participants' preferences, interaction practices, and sustainability evaluations shift over time as Social VR becomes more familiar and platforms mature. Moreover, systematic comparisons of alternative Social VR tools and device configurations (e.g., desktop versus head-mounted displays) could clarify which combinations of technological features and didactic designs best support the sustainability-related outcomes of the academic conference.

More broadly, future studies could test interventions that explicitly foreground ecological information (e.g., providing carbon footprint comparisons between formats) or that systematically vary design features aimed at informal socializing and nonverbal expressiveness, such as avatar realism, spatial audio, and dedicated networking tasks. Such work would help clarify under which conditions Social VR can further decouple the sustainability–quality trade-off, and which conference format is most appropriate for different types and goals of academic events. In doing so, subsequent research can build on the present study's integrated perspective to develop more systematic design frameworks for sustainable and interaction-rich academic conferencing.

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