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Original
Game-Based Metaverse Design for Mountain Sustainability and Inclusive Access / Bin, C., Osello, A.. - In: TRIBELON. - ISSN 3035-1421. - ELETTRONICO. - Special Issue(2026), pp. 54-63. [10.36253/tribelon-4094]

Availability:
This version is available at: 11583/3016229 since: 2026-10-02T09:12:01Z

Publisher:
Firenze University Press

Published
DOI:10.36253/tribelon-4094

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25 October 2026

TRIBELON
RIVISTA DI DISEGNO
UNIVERSITÀ DEGLI
STUDI DI FIRENZE

Special Issue | N. 1 | 2026
LE MECCANICHE DEL GAMING
THE MECHANICS OF GAMING

Citation: C. Bin, A. Osello, *Game-Based Metaverse Design for Mountain Sustainability and Inclusive Access*, in *TRIBELON*, Special Issue, 2026, 1, pp. 54-63.
ISSN (stampa): 3035-143X
ISSN (online): 3035-1421
doi: https://doi.org/10.36253/tribelon-4094
Received: March, 2026
Accepted: May, 2026
Published: September, 2026
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Data Availability Statement: All relevant data are within the paper and its Supporting Information files.
Competing Interests: The Author(s) declare(s) no conflict of interest.
Journal Website: *riviste.fupress.net/tribelon*

GAME-BASED METAVERSE DESIGN FOR MOUNTAIN SUSTAINABILITY AND INCLUSIVE ACCESS

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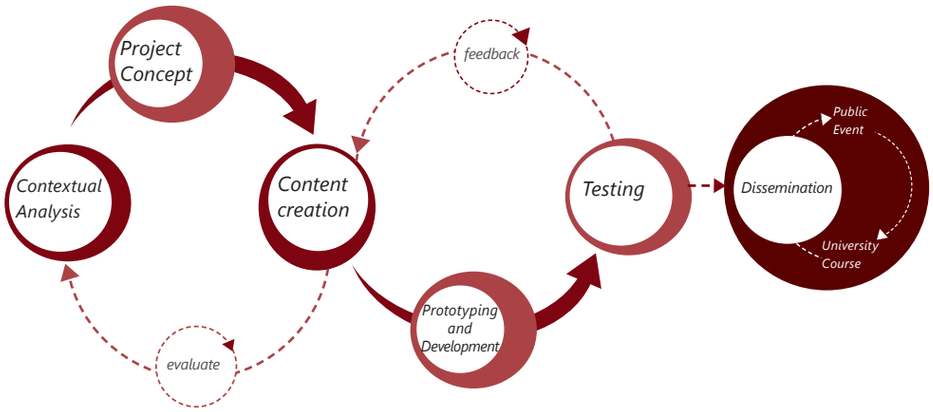
This study investigates the use of game-based design and metaverse environments as tools for mountain sustainability communication and inclusive access. Developed within the NODES – Digital and Sustainable Mountain framework, the research presents a mountain area as a case study to explore how immersive digital systems can support territorial interpretation without replicating physical reality. The project follows a Design Thinking methodology that integrates contextual analysis, data collection, user experience design, and iterative testing. The metaverse environment organises sustainability themes into interactive pathways aligned with the NODES flagship projects. A second application within an educational context tested the transferability of the same approach to inclusive scenarios involving physical and social vulnerability. Results suggest that carefully designed game-based immersive systems can enhance engagement, support experiential access, and contribute to sustainability communication. The study highlights the potential of immersive spaces as flexible infrastructures for territorial activation and inclusive learning.

Keywords: Metaverse, Accessibility, Mountain sustainability, Game-based design, territorial communication.

Game-Based Approaches for Territorial Communication

The increasing adoption of gaming and immersive technologies across different sectors has opened new perspectives for communication, education, and territorial promotion. In recent years, game-based design has progressively moved beyond the entertainment industry and has been adopted in education, healthcare, cultural heritage, and sustainability communication. Interactive environments are increasingly recognised as tools capable of supporting engagement, experiential learning, and public participation[1]. Recent systematic reviews have highlighted the rapid expansion of immersive virtual reality applications in cultural heritage, supported by the increasing accessibility of VR technologies and their growing use for education, public engagement, and cultural applications[2]. Within this evolving landscape, immersive technologies and metaverse platforms provide new opportunities for representing complex territorial systems and communicating environmental issues, particularly in contexts where direct access to places may be limited[3].
Despite the growing diffusion of immersive environments, their use for mountain sustainability communication through structured game-based design remains relatively unexplored. The contribution presented during the event dedicated to the use of gaming across multiple domains explored this gap through the design of a digital experience for promoting mountain territories and social inclusion. Rather than addressing gaming as an end in itself, our research framed gaming and immersive environments as communication and learning infrastruc-

1 Duan et al., *Metaverse for social good*: *A university campus prototype;* Park, Kim, *A metaverse: Taxonomy, components, applications and open challenges.*
2 Rodriguez-Garcia et al., *A Systematic Review of Virtual 3D Reconstructions of Cultural Heritage in Immersive Virtual Reality.*
3 Wang et al., *Gamifying Cultural Heritage: Exploring the Potential of Immersive Virtual Exhibitions.*



1 | *Cervo Valley. On the left, a view from the village of Piedicavallo; on the right, the Cervo River in Rosazza. Photo by Carlotta Bin, 2024.*

2 | *Methodological workflow of the Design Thinking approach adopted for the project.*

tures, capable of supporting awareness and participation[4]. This article aims to describe a research-by-design approach that integrates game-based education, virtual reality (VR), and metaverse platforms to communicate mountain sustainability. The paper presents applied research outcomes developed within the framework of the NODES (Nord Ovest Digitale E Sostenibile) ecosystem, combining territorial analysis, digital representation, and educational experimentation.

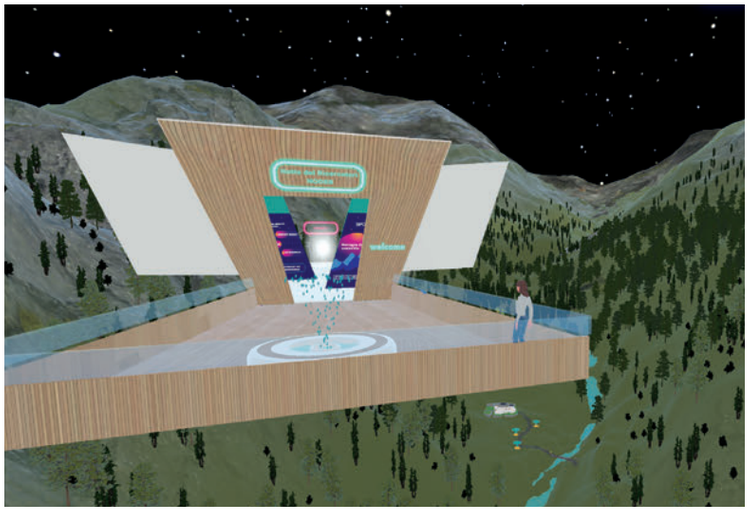
The objectives of the article are threefold: (i) to frame the project within the NODES – Digital and Sustainable Mountain initiative; (ii) to describe the design methodology and technical implementation of a metaverse-based application for territorial communication, using the Valle Cervo as a case study; and (iii) to discuss a second application in the educational domain, where the metaverse was used as a shared space for inclusive learning and assessment. The results contribute to the ongoing discussion on the role of immersive and game-based environments in supporting sustainability-oriented communication and education, without replacing physical experiences but augmenting them[5].

NODES and the Digital and Sustainable Mountain

The project is developed within the framework of NODES – Nord Ovest Digitale e Sostenibile, a large-scale research initiative aimed at fostering digital innovation and sustainability in the north-western regions of Italy. Among

4 Bekoum Essokolo, Robinot, *"Let's Go Deep into the Game to Save Our Planet!" How an Immersive and Educational Video Game Reduces Psychological Distance and Raises Awareness.*

5 Osello et al., *A metaverse between technical and humanistic domains to reach Society 5.0.*



3 | *Digital hub developed for the NODES event within the metaverse platform.*

4 | *Virtual environment of the SMART WEST path. The image shows the starting point of the experience.*

the different thematic areas addressed by NODES, Spoke 4 – Digital and Sustainable Mountain focuses on mountain territories as complex and fragile systems that require innovative tools for communication, management, and development. Mountain regions in the Alpine area are currently facing significant demographic change. The ageing index in the Alpine region is higher than the European average, indicating a growing imbalance between older and younger populations[6]. At the same time, several Alpine municipalities are recording migration dynamics and population decline, particularly in remote areas, with direct implications for service provision and economic sustainability. Geographical constraints complicate access to infrastructure and essential services, especially in rural contexts. In addition, climate change is expected to have stronger impacts in mountain regions, increasing environmental pressure and requiring long-term adaptation strategies[7]. Within this scenario, digital innovation is a strategic instrument to support territorial resilience and socio-economic activation. Spoke 4 is articulated through three flagship projects: SMART WEST concentrates on innovative organisational models for mountain territories, addressing smart working models and the digital infrastructures required to support them in mountain areas, with attention to cybersecurity and the conditions that allow stable hybrid work in geographically isolated areas. SUMMER focuses on the sustainable management of energy and water resources in mountain contexts, using digital monitoring and data modelling to inform decision-making.

INTERFACE develops participatory strategies for the ecological transition of mountain communities, working on regeneration processes and on the strengthening of essential services and local heritage. The common objective is to examine how digital technologies can support sustainability and improve access to territorial knowledge. In this framework, the project is guided by the intention to use digital innovation to improve access to mountain territories and their content. The objective is not to replace physical presence, but to develop a communication strategy that increases awareness and informed interest. By making these areas easier to explore through immersive tools, the project aims to stimulate curiosity and encourage subsequent physical visitation. This approach aligns with recent research highlighting the potential of immersive and game-based environments to support learning, cultural dissemination, and territorial promotion, especially in contexts that are difficult to access or communicate through traditional media[8]. Within NODES, the metaverse is therefore explored as a platform for communication and learning, capable of integrating territorial data and narratives in a shared digital environment.

Valle Cervo, Piedmont

The selected case study for the development of the project is the Valle Cervo, located in the Biella area of Pied-

> *The metaverse therefore functions as a shared interpretive layer that supports awareness and participation, while remaining anchored to the physical territory it represents.*

mont, Northern Italy. The choice of this territory is directly connected to the NODES framework, which operates in the north-western regions of Italy. Valle Cervo represents a mountain area characterised by a strong environmental identity and a layered historical development (fig. 1). The valley is crossed by the Cervo River, from which it takes its name, and its settlements are distributed along the narrow valley floor. The landscape combines alpine morphology with a built heritage shaped by small villages, such as Rosazza, known for its distinctive architecture and symbolic elements. During the nineteenth and early twentieth centuries, the area experienced economic vitality linked to local manufacturing activities, including the textile and hat industry, which contributed to shaping both the settlement structure and the local economy. Over the course of the twentieth century, this productive system gradually weakened. Historical documentation of the Biellese territory records the progressive transformation of settlements and industrial landscapes[9]. Despite this historical richness, the valley has progressively faced demographic decline and a reduction in local economic activity. Similar to many Alpine territories, remote settlements are affected by ageing, migration, and the weakening of local services[10]. These dynamics generate spatial marginalisation and reduce the capacity of the territory to attract new residents or investments. The case study was selected as a territorial laboratory to test digital tools as instruments for communication and activation. The aim was to explore how immersive and game-based environments could reinterpret the valley's environmental and cultural heritage within a structured digital framework.

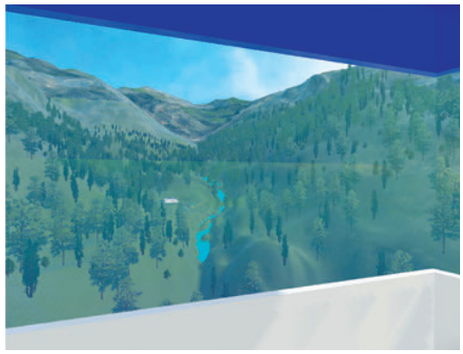
Objectives and Expected Impacts

The project was developed with the aim of generating a positive impact on the sustainability of the Valle Cervo through digital and immersive tools. Three main dimensions of impact were identified: territorial, economic, and social. At the territorial level, the project aims to improve the accessibility of environmental and spatial information. Through the digital modelling of the valley and the organisation of content within a shared immersive platform, data elements become more interpretable. The metaverse environment supports the interoperability of models, facilitating the communication of complex territorial features to different user groups. At the economic level, the initiative contributes to the broader digitalisation of mountain areas promoted within Spoke 4. The development of immersive environments and interactive applications can support new forms of territorial valorisation, including educational tourism and cultural dissemination. The project also contributes to increasing the visibility of the area. At the social level, the project seeks to foster community involvement and wider accessibility to mountain heritage. By enabling remote access to the valley through immersive tools, the metaverse platform allows different categories of users to explore the territory regardless of geographical or physical constraints. In this sense, the digital environment becomes a complementary space for participation and knowledge exchange[11].

Metaverse and Game-Based Approach

The project adopts the metaverse as a digital environment for communication. In this context, the metaverse is understood as a shared three-dimensional virtual space in which users, represented by avatars, can interact with environments and with each other[12]. Unlike early interpretations that associated the metaverse primarily with entertainment or escapism, recent research highlights its potential as an infrastructure for education, collaboration, and territorial communication[13]. In the framework of the Digital and Sustainable Mountain initiative, the metaverse is not conceived as a substitute for physical experience. It is used as a space that allows users to access territorial content remotely, explore spatial reconstructions, and interact with digital representations of landscapes and heritage elements. The integration of a game-based approach strengthens this communicative dimension. Game-based education refers to the use of game princi-

6 Alpine Convention, *Quality of Life in the Alps. Tenth Report on the State of the Alps (RSA 10)*, pp. 18-20.
7 *Ivi*, pp. 20-23.
8 Jaung, *Digital forest recreation in the metaverse: Opportunities and challenges;* Bin, Cassis, Osello, *Metaverse education: Immersive VR exploration of mountain heritage and culture.*
9 Scarzella, *Immagini del vecchio Biellese.*
10 Alpine Convention, *Quality of Life in the Alps. Tenth Report on the State of the Alps (RSA 10)*, pp. 33-49.
11 Wei, *Systematic literature review of using virtual reality as a social platform.*
12 Duan et al., *Metaverse for social good: A university campus prototype*, pp. 153-154.
13 Park, Kim, *A metaverse: Taxonomy, components, applications and open challenges*, pp. 4224-4226.



5 | *Virtual environment of the SUMMER path. The image shows the view from inside the moving cable car.*

6 | *Virtual environment of the INTERFACE path. The image shows an interactive task in which users decide whether to preserve or cut a tree.*

ples in non-gaming contexts to enhance engagement and learning outcomes. Rather than focusing on competition or reward systems alone, this approach emphasises interaction, exploration, and feedback as mechanisms for active learning[14]. In the Valle Cervo application, game-based elements were implemented to guide users through the virtual environment. The gamification strategy was structured around progression, task completion, and decision-making. Users were not passive observers, but were required to actively engage with content through quizzes and environmental challenges. The use of branching activities created a narrative sequence that reinforced learning objectives while maintaining user autonomy. Beyond interactive mechanics, the experience was organised through a narrative progression that connected the introductory hub with the three thematic pathways, supporting exploration and the interpretation of territorial content. The combination of metaverse infrastructure and game-based strategies enables experiences that are not constrained by physical distance or temporal limitations. Users can access the valley remotely, revisit content, and interact with others in real time[15]. This characteristic is particularly relevant in mountain contexts, where accessibility can be limited by geography, infrastructure, or personal conditions. Immersive environments become tools for sustainability communication. They allow complex territorial systems to be represented in an interactive format, facilitating understanding without oversimplifying the content. The metaverse therefore functions as a shared interpretive layer that supports awareness and participation, while remaining anchored to the physical territory it represents.

Methodology

The project was developed following a Design Thinking approach, conceived as an iterative and non-linear process structured around five main phases (fig. 2). This methodology was adopted to ensure coherence between territorial context and user experience. The first phase consisted of contextual analysis. This included desktop research and field surveys conducted in the Valle Cervo. The aim was to identify the key environmental, historical, and spatial elements to be communicated, as well as to frame the project within the broader objectives of NODES and its flagship initiatives. This analytical phase allowed the definition of the core needs of the project and the identification of the target users. Understanding the intended audience was considered essential for structuring both

[14] Khan et al., *Systematic review on gamification and cultural heritage dissemination.*
[15] Hatami et al., *A survey of the real-time metaverse: Challenges and opportunities.*

content and interaction. The second phase involved defining the project concept.

From the beginning, the immersive environment was conceived as a tool to support interpretation rather than replication. The objective was not to reproduce the valley as realistically as possible, but to create a digital layer that could improve users' understanding of the territory. Based on the results of the analysis, the project objectives were defined and the metaverse was selected as the main communication platform. Spatial.io, an open and web-based platform, was chosen because it supports multi-user access through browsers and VR headsets and can be easily deployed without complex local installations.To support this approach, the virtual environment was designed using a low-poly visual style, characterised by simplified geometries and flat colour surfaces. Instead of aiming for photorealism, this choice reduced unnecessary visual complexity, improved spatial orientation, and directed users' attention towards the interactive elements of the experience. As a result, users were encouraged to focus on interaction and the interpretation of the territory rather than on visual realism. The third phase concerned ideation and digital modelling. During this stage, source materials were collected and three-dimensional elements were developed. Landscape components and architectural references were modelled using Blender and InfraWorks. In parallel, the gamification structure of the project was defined. This included the design of activities, the sequence of interactions, the timing of the experience, and the path that users were expected to follow within the virtual environment. The visual composition of each scene was also established during this phase. The fourth phase consisted of prototyping and development. Particular attention was given to user experience (UX) and user interface (UI) design. Multimedia content was integrated into the environment, including images, 360-degree photographs, audio guides, ambient sounds, and video materials. Graphic communication elements such as icons and visual markers were designed to support navigation. Interactive functions were implemented, enabling users to manipulate objects and activate content within the scene. This development stage was carried out using Unity Engine software, combined with the Spatial Creator Toolkit's plugin for integration into the metaverse platform, and Adobe Pack tools for graphic production. The final and crucial phase involved testing. After the application was configured for VR headsets, user testing sessions were conducted with participants experiencing the environment both in immersive mode and through desktop access. Feedback was collected and analysed to evaluate clarity, interaction fluidity, and overall usability. The results of these tests were fundamental in refining and improving the experience.

Dissemination and Immersive Experience Design

Following the design and testing phases, the project was publicly presented during the European Researchers' Night 2024 in Turin. An exhibition stand was installed in the courtyard of the Royal Palace of Turin, where visitors were invited to experience the metaverse environment using Meta Quest 3 headsets. The event provided an opportunity to test the immersive application with a heterogeneous audience and to observe real-time interaction in a public setting. The virtual experience begins with the user's avatar positioned inside a shared Spatial environment. Instead of presenting independent virtual scenes, the experience was conceived as a narrative journey. Users first entered a central hub introducing the project and its objectives, explored the exhibition space, and then selected one of the three thematic pathways. This narrative progression guided exploration while allowing users to actively interact with the different environments. As recent studies suggest, storytelling in XR environments can transform users from passive observers into active participants, strengthening engagement with cultural content[16]. The initial setting functions as a digital hub dedicated to the NODES project (fig. 3). The space takes the form of a suspended architectural structure floating above a virtual model of the Valle Cervo. The scene is set at night, intentionally aligned

7 | *Examination session. Direct interaction through VR headsets and presentation of projects within the metaverse environment. Photo by Carlotta Bin, 2024.*

[16] Song et al., *A Phenomenology Study of Transmedia Museum Storytelling and Gamification through XR Technologies.*

8 | *Student-designed virtual environments developed within the "Virtual Reality for Disability" course. The images show different mountain paths with interactive elements and landscape exploration.*

with the atmosphere of the Researchers' Night event. From the balcony of the structure, users can look down and perceive the valley model below, reinforcing the spatial relationship between the virtual platform and the physical territory. Guided by light cues and graphic elements, users move inside the structure, where a digital exhibition introduces Spoke 4 and its objectives. Informational panels and visual materials present the framework of the Digital and Sustainable Mountain initiative. At the end of the exhibition space, users encounter three portals corresponding to the three flagship projects: SMART WEST, SUMMER, and INTERFACE. Each portal leads to a different immersive path within the valley. The SMART WEST path opens in a daytime mountain landscape inspired by the Piane di Piedicavallo area. A visible trail on the ground and graphic markers guide the user along a predefined route. Along the path, interactive platforms present short quizzes related to smart working in mountain contexts. The activity encourages users to reflect on the feasibility of remote work in geographically isolated areas. At the end of the route, users reach a mountain hut designed according to sustainability principles. Inside the hut, 360-degree images and descriptive content illustrate integrated systems that enable smart working, including energy-efficient solutions and digital connectivity (fig. 4). The SUMMER path leads into a forested environment during daylight. The central element is a semi-transparent structure inspired by the morphology of a glacier, characterised by fragmented surfaces in shades of blue. This structure functions

as the thematic hub of the SUMMER project. After interacting with the hub, users activate a cable car that transports them to a higher altitude. During the ascent, the surrounding landscape becomes visible. At the arrival point, visual materials and data related to local glaciers are presented, connecting environmental change with resource management (fig. 5). The INTERFACE path takes place in a wooded area and focuses on the sustainable wood supply chain.

The interactive activity invites users to walk through the forest and access information linked to individual trees. Each tree contains data regarding species, age, and ecological role. Based on this information, users are asked to decide whether to preserve or fell the tree. The objective is to simulate decision-making processes related to sustainable forest management, encouraging critical reflection rather than simple task completion (fig. 6). Across all three paths, the immersive design prioritises clarity and orientation. Graphic cues, controlled spatial progression, and interactive feedback structure the experience without overwhelming the user. The duration of each path is limited to maintain engagement within a public event context. The dissemination phase showed the potential of immersive and game-based environments to communicate complex territorial themes to a broad audience.

Transferability of the Game-Based Approach

To test the transferability of the proposed game-based design approach beyond territorial communication, a second implementation was developed within the course *Virtual Reality for Disability* at Politecnico di Torino, part of the Big Global Challenges programme. In this context, the metaverse infrastructure was adapted to address conditions of physical and social vulnerability. Students were required to identify a specific form of disability and to translate real user needs into interactive spatial solutions. The mountain environment was intentionally maintained as the operational setting, reinforcing the idea of mediated access to natural contexts for individuals who may experience mobility or participation constraints. Recent studies indicate a growing research interest in the application of metaverse environments within healthcare and rehabilitation contexts, particularly in relation to accessibility and remote interaction[17]. The course explored how the same digital framework could simulate experiential access and support engagement in controlled settings. For the academic year considered in this study, the design brief was inspired by the animated series *Heidi*. The focus was placed on the relationship between Heidi and Clara, a child living in an urban environment with motor limitations. The narrative was interpreted as a design metaphor: the act of bringing Clara to the mountains was reimagined as the use of immersive technologies to mediate access to environments otherwise difficult to experience. Students developed interactive experiences within the digital reconstruction of the Valle Cervo. Each group structured a targeted activity in line with specific experiential or support objectives. Proposed scenarios included guided mountain walks aimed at environmental awareness, zipline simulations to stimulate spatial perception, climbing exercises conceived as motor training support, and gardening activities designed to enhance sensory engagement. The final examination was conducted entirely within the shared metaverse space using VR headsets. Students presented their projects through dedicated portals, allowing instructors and participants to experience the activities directly (fig. 7). This second implementation confirms that the game-based methodology adopted for territorial communication can be adapted to inclusive educational contexts. The metaverse operates as a flexible digital layer that supports access and extends experiential participation beyond physical constraints (fig. 8).

Conclusion

This study presented the development and application of a game-based metaverse environment designed to support mountain sustainability communication and inclusive educational practices. Through the case of the Valle Cervo, the project demonstrated how

[17] Wu, Chen, Zhang, *Topic prevalence and trends of metaverse in healthcare: A bibliometric analysis.*

immersive digital environments can function as structured tools for territorial interpretation.

The implementation within the NODES framework showed that a game-based structure can enhance public engagement with complex territorial themes. By organising content into interactive paths aligned with the flagship projects, users were able to explore sustainability issues related to smart working, resource management, and ecological transition in an accessible format.

Interactive tasks and progressive activities increased motivation and sustained attention, strengthening the overall learning experience. The digital system was conceived not as a substitute for physical visitation, but as a complementary layer capable of stimulating informed interest in the mountain context.

The educational application confirmed the transferability of the same methodological approach. When adapted to contexts of physical or social vulnerability, the metaverse structure supported inclusive design scenarios by reinterpreting the mountain as a structured immersive environment. Rather than replicating therapeutic settings, the experiment demonstrated how game-based interaction can facilitate experiential inclusion within controlled digital contexts. Across both implementations, the metaverse functioned as a flexible infrastructure integrating territorial representation and user interaction. The iterative design process and user testing phases highlighted the importance of clarity and spatial orientation in immersive systems. Taken together, the two applications suggest that carefully designed game-based methodologies can support sustainability communication while extending access to complex territorial environments. Rather than reproducing the physical mountain, the project proposes an augmented digital layer that facilitates interpretation and participation. Further research is needed to assess long-term user impact and to evaluate the integration of such systems within broader territorial strategies.

9 | *Public dissemination of the project during the European Researchers' Night 2024 in Turin. (a) Visitors experiencing the immersive environment using VR headsets; (b) NODES exhibition stand presenting the three flagship projects SMART WEST, SUMMER, and INTERFACE.*

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