# Immersive VR-Driven Landscapes: Exploring Climate-Adaptive Ecosystem Design

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**Abstract:** This paper investigates the Icelandic turf house as a conceptual model for adaptive, climate-responsive design strategies explored through immersive narratives. The research integrates Virtual Reality (VR), point cloud technology, and diverse ecological datasets to establish a speculative framework for understanding and designing symbiotic systems. Leveraging the Terraforming Interface – a computational framework tailored for cross-scalar ecological exploration – this research transforms VR into an interactive medium for engaging with dynamic, multi-layered processes. High-resolution point clouds enriched with microbial, vegetative, and behavioral data allow for real-time exploration of ecological interdependencies within immersive environments. Narrative-driven VR scenarios visualize speculative futures, reimagining architecture as an active participant in ecological networks. By advancing a more-than-human perspective, this approach challenges static design paradigms, emphasizing resilience, cohabitation, and adaptive strategies for addressing climate change. The findings demonstrate the potential of architecture as a living, responsive system that bridges the divide between the built and unbuilt, offering pathways for innovation in sustainable and climate-adaptive design.

**Keywords:** Virtual reality (VR), climate-responsive design speculation, multispecies cohabitation, data-driven design, point-cloud technology, speculative ecosystem simulation

## 1 Introduction

Climate change is profoundly reshaping environments, particularly in regions undergoing significant transformations such as shifts in vegetation patterns, glacial retreat, and the reconfiguration of ecosystems (IPCC 2023). These changes underscore the urgent need for dynamic and adaptive approaches to landscape and architectural design that can respond to evolving environmental and ecological conditions (LIU et al. 2024). Addressing this challenge requires a paradigm shift that transcends traditional, human-centered perspectives and embraces the interconnected systems of humans, nonhumans, and the broader environment (MACKENZIE & JEGGO 2019).

The Icelandic turf house serves as a conceptual testbed for investigating the relationship between habitation and environmental information transfer. Rather than focusing solely on multispecies cohabitation, this research examines how computational tools can reveal hidden ecological interactions and facilitate climate-adaptive design strategies (Fig. 1). These vernacular structures exemplify a deep integration of ecological processes, material flows, and multispecies cohabitation, making them ideal conceptual models for exploring adaptive and symbiotic design (CARLSEN 2022). By focusing on the interconnected relationships within these systems, this research expands the discourse on dynamic forms of architecture and landscape design, advancing strategies for resilience and cohabitation in the face of rapid environmental change (ARONSON et al. 2020).

Central to this inquiry is the Terraforming Interface (Fig. 5), a speculative computational framework that integrates Virtual Reality (VR), point cloud modeling, and ecological data (FRICKER 2024). While VR has traditionally been used as a visualization tool in architecture

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and landscape design, this research pushes its boundaries, using immersive, visionary environments to reveal the hidden dynamics of ecological systems and facilitate a shift away from human-centered design paradigms. The Terraforming Interface connects multi-scale datasets – spanning microbial networks, material behaviors, and macro-level environmental conditions – onto digital models, enabling designers to interact with complex systems in real time (GRISIUTE & FRICKER 2020). This approach fosters a deeper understanding of the temporal and spatial interdependencies that define landscapes and built environments.

Conducted in collaboration with the turfiction project (turfiction.org), this research conceptualizes turf houses as "superorganisms" that mediate relationships among humans, animals, soil, fungi, and other nonhuman agents. By examining these structures through a computational and ecological lens, the study seeks to dissolve artificial boundaries between the built and unbuilt, exploring potentials of a unified approach to design that integrates ecological processes as intrinsic to the creative process. Immersive storytelling and speculative design further emphasize the potential of VR to reframe architecture and landscape as dynamic participants in ecological systems, advancing a more-than-human perspective in response to the challenges of the Anthropocene (FRICKER 2018).

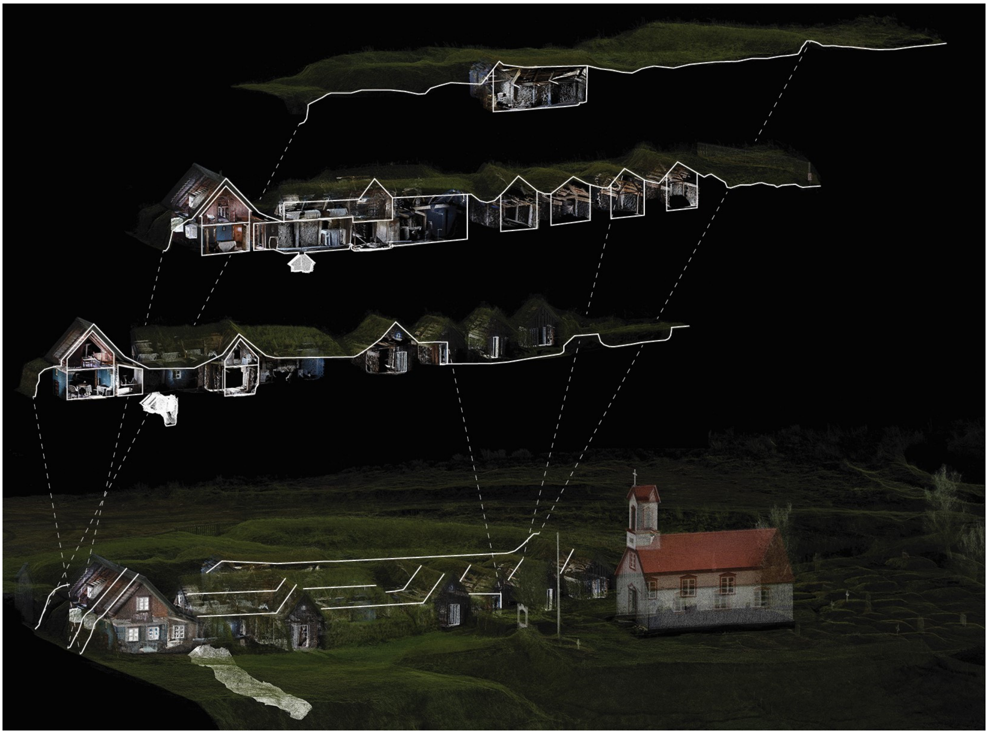

**Fig. 1:** Point cloud scan of the Icelandic turf house at Keldur, showcasing generated sections that reveal spatial interconnections and ecological dynamics. The lower section showcases the spatial conditions for human interactions within the architectural framework, while the upper sections highlight the spatial conditions for the microbial processes and energy flows (Image credit: Chaowen Yao and Pia Fricker, Aalto University).

## 2 Background

The Icelandic turf house represents a vernacular form of design deeply intertwined with its surrounding environment, dating back to the settlement period in the 9th century. Constructed from locally sourced materials – turf, stone, and driftwood – these structures embody a symbiotic relationship between human habitation and the natural landscape. While their ecological integration highlights principles of sustainability and adaptability, they also reflect a pragmatic response to the environmental and material constraints of early Icelandic society (HAFSTEINSSON 2010).

Turf houses served as an effective solution to Iceland's harsh climate. The insulating properties of turf, coupled with its regenerative capacity, provided warmth and stability in a resource-scarce environment (ÓLAFSSON & MAGNÚSSON 2004). These structures fostered ecological micro-networks through the use of sod, roots, and microbial-rich soil, which supported a variety of plant, fungal, and microbial life (KORNÉL 2013). Functionally, they acted as dynamic systems, continuously evolving with their environment as weathering and erosion demanded ongoing maintenance. This adaptive quality demonstrates how design can mediate relationships between human needs and ecological processes.

However, these strengths were accompanied by significant challenges, particularly regarding living conditions. Nineteenth-century reports detail overcrowding within turf houses, with large families confined to small, poorly ventilated spaces. These conditions facilitated the spread of infectious diseases such as scabies and tuberculosis, exacerbated by poor hygiene and limited access to medical care. Nutritional deficiencies, compounded by the isolation of many communities, further weakened resilience. Over time, these health concerns, along with the labor-intensive maintenance of turf houses, contributed to their decline, as materials like timber and concrete became more accessible and culturally preferred.

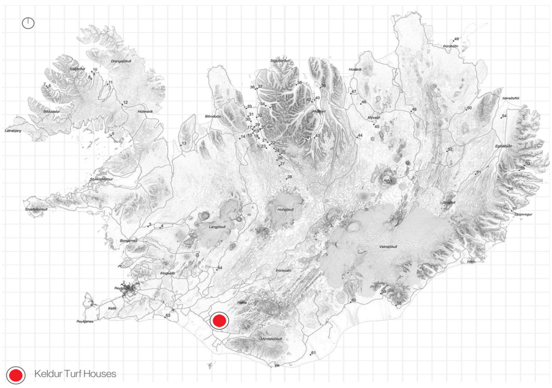


**Fig. 2:**
Location of case study and geographical mapping of the currently existing 64 turf houses (including ruins) in Iceland (Frischknecht Ansbjerg 2022)

Despite these historical challenges, the turf house remains a valuable conceptual model for contemporary design research. Its ecological and material embeddedness offers critical insights into multispecies cohabitation, resource efficiency, and regenerative systems – concepts increasingly relevant in the face of global environmental crises. The Keldur turf house, one of the oldest preserved examples in Iceland (Fig. 2), illustrates this duality. Located in southern Iceland, Keldur was historically a hub of human activity and ecological exchange, with interconnected buildings linked by passageways facilitating diverse uses (Fig. 1). Today, it exists primarily as a museum site, its once-active ecological systems now dormant but ripe for speculative reimagination.

# 3 Methodology

This study adopts a multi-faceted methodology to investigate the Icelandic turf house as a speculative model for adaptive and symbiotic design. By integrating interdisciplinary fieldwork, computational modeling, and immersive storytelling, the research examines the interconnected systems of these historical structures to uncover new pathways for landscape and architectural innovation and re-imagination. The methodology emphasizes transforming static point clouds into dynamic, interactive frameworks for interconnected systems, enabling users to explore and interact with these systems in real time.

**Fig. 3:** Immersive storytelling installation showcasing the narrative-driven design of the Terraforming Interface in an exhibition context. This setup extends the singular VR experience into a collective spatial environment, allowing participants to interact and exchange ideas within a shared immersive installation. Using three synchronized projectors supported by a sound installation, the installation fosters engagement among stakeholders from diverse backgrounds, emphasizing the societal and collaborative dimensions of adaptive design (Image credit: Pia Fricker, Aalto University).

## 3.1 Fieldwork and Data Collection

Data collection commenced with terrestrial laser scanning (TLS) at the Keldur site, capturing high-resolution point clouds that detailed the spatial and architectural complexity of the turf house. These scans served as a comprehensive structural framework, supporting subsequent computational analysis and immersive modeling.

In parallel, microbial samples were collected from various parts of the turf house, including walls, floors, and dormant ecological niches. These samples complemented data from ongoing research collaborations, enabling a more extensive understanding of microbial diversity and ecological roles. DNA sequencing and genomic analysis revealed symbiotic networks among microbes, soil, and plant matter, which provided the biological foundation for the computational models. This multi-layered integration bridged the micro and macro scales of the turf house ecosystem, establishing a dynamic framework for the study.

Beyond microbial interactions, the study extended its scope to investigate the role of vegetation and its integration within the turf house system. Vegetation was analyzed for its contributions to structural stability, nutrient cycling, and ecological regeneration, framing the turf house as a "superorganism." The inclusion of animals as active participants further emphasized the interconnectedness of the ecosystem. Their behaviors, contributions to nutrient cycles, and symbiotic interactions with the structure were considered pivotal to understanding the dynamic cohabitation within the turf house.

Human interaction was analyzed from both cultural and design-driven perspectives. This dual approach contextualized the turf house as a cultural artifact reflecting historical practices of symbiosis while exploring its potential as a model for adaptive design. By synthesizing these dimensions, the study informed four distinct VR projects, each focused on a specific facet of the turf house ecosystem: microbial interactions, vegetation dynamics, animal activity, and human-mediated design adaptations (Fig. 3).

## 3.2 Computational Modeling and VR Integration

Building on the fieldwork datasets, this study employs computational techniques to transform static point clouds into dynamic, data-enriched models of the turf house ecosystem. These enriched models enable multi-scale exploration and real-time interaction within a VR environment, reimagining architecture as a dynamic participant in ecological systems.

An experimental design workflow allows enhancing the gathered high-resolution point clouds of the Keldur turf house with ecological datasets, including microbial networks, vegetation dynamics, and animal behaviours. This workflow makes use of the visual effect software Houdini, as well as the game engine Unity.

Terrestrial laser scan (TLS) data collected from the Keldur turf house was processed using a Houdini procedural pipeline, enabling its transformation into a structured point-cloud dataset. This dataset was then integrated into Unity's Visual Effect (VFX) Graph, a real-time GPU-based particle system optimized for dynamic point cloud rendering and interaction. The use of VFX Graph allows quantitative environmental data (such as microbial diversity and soil conditions) to be mapped onto spatial models, translating ecological parameters into visual and interactive elements within the VR environment. Unity VFX Graph is based on the mathematical manipulation of data points, and therefore proves to be an excellent tool to create point cloud interactions.

As a programming interface itself, VFX Graph allows to import any kind of quantitative data and use it in mathematical operations. To illustrate the concept: The Terraforming Interface employs parameterized agent interactions informed by empirical ecological data collected from site analysis. Microbial populations, for instance, are not randomly assigned but rather modeled based on observed distribution patterns, with population densities influencing visualized microbial colonies in real time. This method ensures that VR-based interactions align with site-specific ecological logic, making the visualization both immersive and grounded in real-world data dynamics. Thus, creating data-driven illustration of microbe populations within turf-house walls. The numerous features of Unity as a game engine also provide limitless ways to present qualitative data. Exemplary, site-specific sound recordings may be played when reaching a certain area.

Combining the discussed techniques with virtual reality creates an immersive, data-driven, and exploratory experience. Every part of the program may influence another. A VR user may "touch" the point cloud, which changes numeric values in the calculation of the VFX Graph – creating movement. The same automatism may distort the sound in the virtual environment. This enables users to navigate between scales and interact with complex interdependencies (ZHOU et al. 2023).

The point cloud models serve as a spatial scaffold that dynamically integrates biodata layers (e. g., microbial, vegetative, and climate datasets). The Terraforming Interface employs attribute-based segmentation, allowing ecological datasets to be linked to specific spatial features. For example, vegetation clusters are mapped to corresponding microbial conditions, revealing spatial interdependencies through interactive visualization. This multi-layered integration enables users to navigate through different scales of ecological complexity, observing real-time interplays between materiality and environmental data. Temporal scenarios allowed users to explore speculative futures, simulating long-term ecological changes or the impact of design interventions. By positioning VR as an interactive, exploratory medium, this approach advances a novel framework for adaptive design (Fig. 4).

Unity, as a game engine, offers an extensive range of features for developing immersive, data-driven experiences. This project selectively employed a subset of these tools, focusing on real-time point cloud interaction and dynamic environmental modeling. Future research could explore additional interaction techniques, such as eye-tracking, body movement integration, or real-time point cloud generation, to further enhance user engagement with ecological datasets.

Equally critical is the integration of rigorous scientific research and narrative-driven methodologies in virtual reality environments. The effectiveness of a data-driven experience relies not only on technical execution but also on the accuracy of the underlying datasets and the clarity of their representation. Unity and Houdini serve as powerful tools for translating complex environmental data into interactive spatial experiences, but their value is contingent on methodologically sound data collection and thoughtful storytelling that effectively conveys ecological dynamics.

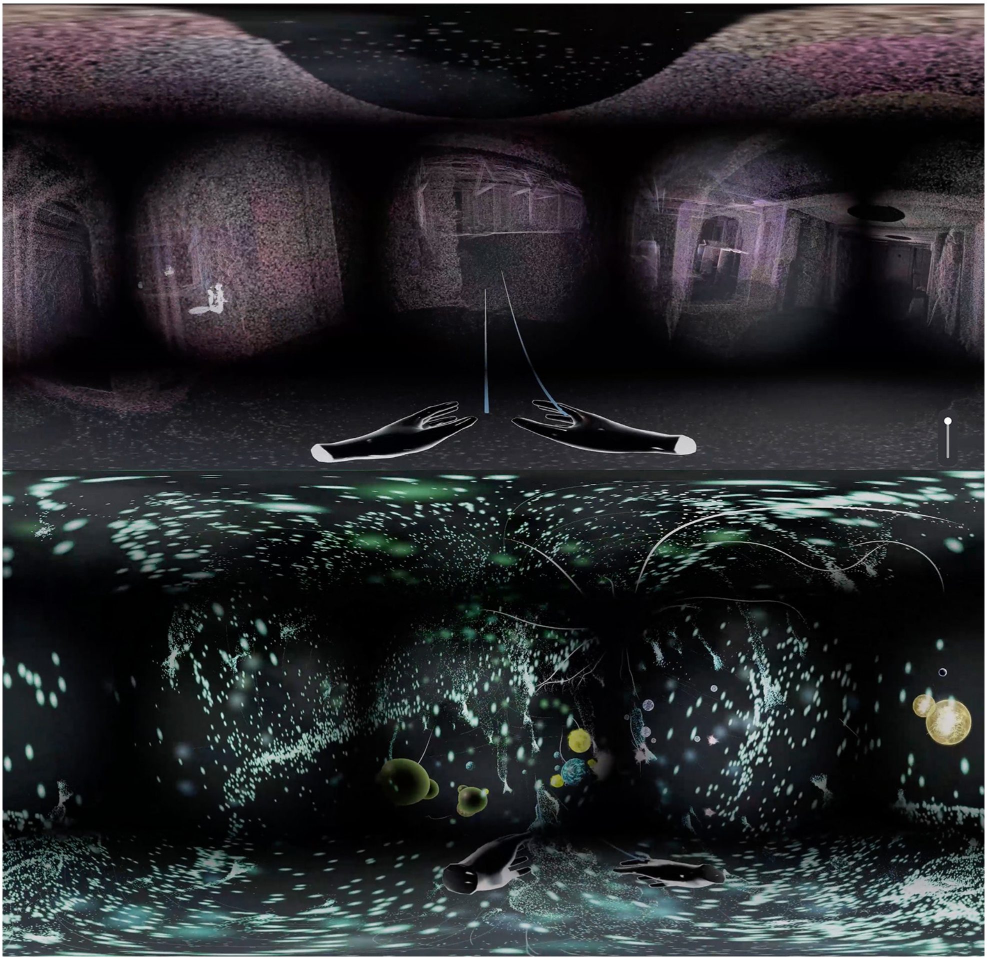

**Fig. 4:** Visualization of the multi-scale VR experience exploring the interdependencies between humans, animals, and microbial life within the Icelandic turf house ecosystem. The upper image depicts the responsive point cloud representation of the turf house, where portals guide users to the microbial world shown in the lower image. As illustrated in chapter 3.2. both scenes are interconnected and influence each other. Both worlds co-exist and evolve within the spatial narrative, encouraging users to shift between scales through sound cues. By interacting with these environments, users leave traces that influence and reveal the dynamic relationships between microbes, humans, and animals, emphasizing their spatial and ecological relevance (Image credit: Nils Dräger, Kerui Jiang, Yihan Lou, Ella Vourela, Aalto University).

### 3.3 The Terraforming Interface

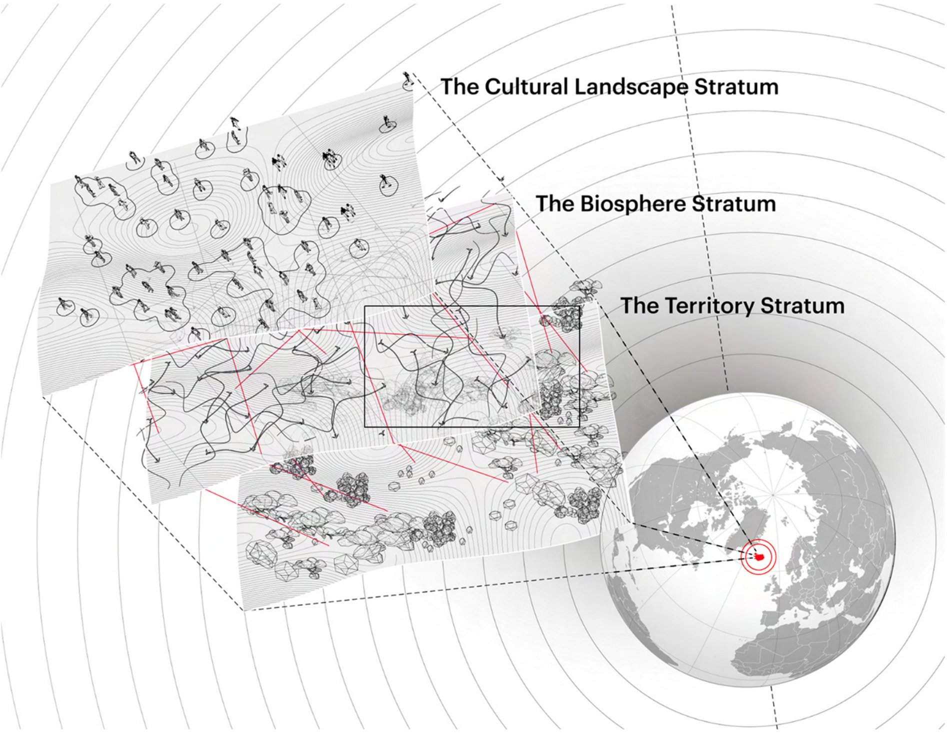


**Fig. 5:** Visualization of the Terraforming Interface, depicting its three interconnected strata: the Territory Stratum, the Biosphere Stratum, and the Cultural Landscape Stratum. The diagram emphasizes the methodological focus on cross-scalar navigation and interconnected processes, which are explored interactively through the VR environment (Image credit: Tina Cerpnjak & Pia Fricker, Aalto University).

The Terraforming Interface integrates storytelling, computational modeling, and dynamic data into a cohesive framework for design speculation. Developed as a flexible method, it has been applied across diverse research contexts to explore cross-scalar ecological relationships and speculative futures (FRICKER 2018, 2019). In this study, the framework is tailored to the local context to investigate symbiotic and potentials for climate-responsive design. The Terraforming Interface operates on two dimensions: 1. Terraforming: Beyond ecological or geological modification, terraforming reflects the integration of natural and urban systems, emphasizing their co-dependence. 2. Interface: The Interface synthesizes multi-scale data into a navigable framework, transforming static datasets into interactive strata for real-time exploration (Fig. 5). Central to this methodology are three interwoven strata that underpin the VR environment:

- The Territory Stratum: Represents global and territorial systems, emphasizing the broader spatial networks influencing local ecosystems.

- The Biosphere Stratum: Highlights ecological processes such as microbial networks, nutrient flows, and vegetative cycles, showcasing the interdependencies within the turf house's ecosystem.
- The Cultural Landscape Stratum: Focuses on localized human and nonhuman cohabitation, reflecting cultural practices and adaptive design strategies.

These strata are dynamically connected within the VR environment. Users navigate between them through interactive elements such as portals and sound cues, transitioning between the architectural structure and microbial scales. By integrating this framework into the VR project, users experience the multi-layered dynamics of the Icelandic turf house while gaining insights into symbiotic design strategies (FRICKER 2022, 2013).

## 4 Spatial Storytelling

Spatial storytelling forms the core of this research's immersive design methodology, engaging users in dynamic narratives that foreground the agency of nonhuman actors and their interactions with architectural systems. Each VR scenario was developed to explore a specific aspect of the turf house ecosystem, including microbial activity, vegetative dynamics, animal behaviors, and human-mediated adaptations.

One scenario begins with the turf house depicted as a dormant structure; its ecological networks fragmented. As users interact with the VR environment, they metaphorically "restore" its ecological functionality (Fig. 4). Dynamic simulations visualize processes such as microbial regrowth, nutrient cycling, and vegetative adaptation, transforming the structure into a pulsating, adaptive "superorganism."

The narrative-driven design invites users to actively shape the ecosystem's dynamics by experimenting with variables such as soil composition, microbial diversity, or vegetation density. These interactive experiences challenge anthropocentric perspectives, emphasizing the interconnectedness of human and nonhuman actors. Through storytelling, the Terraforming Interface fosters a deeper understanding of symbiotic relationships, advancing design strategies that prioritize resilience and cohabitation.

## 5 Conclusion and Outlook

This research goes beyond the conventional use of VR as a tool for visualization by positioning it as an interactive medium for data-driven exploration and speculative design. The integration of high-resolution point clouds and ecological datasets within VR environments establishes a precedent for using immersive technologies to interrogate complex environmental systems. Unlike static design paradigms, this dynamic approach allows for iterative exploration and the discovery of patterns across scales. It highlights the potential of VR to transition from a representational medium to a participatory platform, enabling designers, researchers, and stakeholders to engage critically with the interconnectedness of human and nonhuman systems.

Through narrative-driven interactions and speculative scenarios, the Terraforming Interface enables a reimagining of architecture not as a fixed construct but as a dynamic participant in ecological networks. This shift invites designers and researchers to consider new materials, forms, and systems that evolve in response to environmental change – from walls enriched by microbial networks to landscapes that regenerate through symbiotic cycles. Bruno Latour's call to rethink the modernist divide between nature and culture resonates deeply with the aims of this study. In *Down to Earth: Politics in the New Climatic Regime* (2018), Latour advocates for an approach that acknowledges the entanglement of humans and non-humans within shared systems. This research exemplifies that entanglement, proposing architectural strategies that dissolve boundaries between the built and unbuilt, embracing a unified ecological framework. The implications of this work call for a fundamental reorientation of architectural practice – towards materials and systems capable of learning, adapting, and responding to the unpredictable challenges of climate change. Future research will expand on these foundations by exploring applications in urban contexts, integrating hydrological and energy networks, and further developing computational tools for co-creative processes. By imagining architecture as a living, adaptive participant in its environment, this research invites stakeholders across disciplines to envision new paths toward resilience and sustainability. As Latour reminds us, the urgent task is to design for the "critical zone" where life unfolds – a challenge that demands both humility and bold innovation (Latour et al., 2021). This study offers a starting point, demonstrating how speculative tools like the Terraforming Interface can help us grapple with the complexity of this shared endeavor.

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