Sensing the Invisible

Architectural approaches to sonifying microbial life in Icelandic turf houses through VR

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Icelandic turf houses, inhabited for over a millennium, embody a distinctive form of sustainable architecture deeply integrated with ecological processes, hosting complex microbial ecosystems. Beyond their historical and cultural significance, these houses offer an invaluable opportunity to investigate the symbiotic relationships between built environments, natural systems, and the microbial agents that contribute to their unique ecological balance. In the face of the climate crisis, this research addresses the urgent need for adaptive, resilient design approaches that embrace a more-than-human perspective. This investigation explores the use of an immersive virtual reality (VR) environment to actively engage with the imperceptible biochemical processes present in these historic structures. By layering these multiple data sources, the research seeks to craft an evolving spatial, interactive experience that situates microbial agents and material cycles as active participants that prompt new understandings of architecture's role within broader ecological systems. This research moves beyond traditional approaches to digital heritage or data-driven narratives by introducing novel forms of interaction and foregrounding non-human agents as active contributors. Instead, it establishes a more holistic, interactive mode of engagement that highlights architecture's potential to mediate complex ecological relationships.

Keywords: *Virtual reality, More-than-human design, Interactive narratives, Data sonification, Ecological systems, Digitized heritage.*

INTRODUCTION

Building with turf is a tradition that dates back to the earliest settlement of Iceland, an adaptation to the local climate and the resources available (Stefánsson, 2019). It was the predominant form of building until it was eradicated in the 20th century, when many turf buildings were allowed to fall into disrepair. The National Museum of Iceland has since acquired many and began preservation efforts, in collaboration with the University of Iceland (Hafsteinsson and Jóhannesdóttir, 2023). While the turf house has its shortcomings as a dwelling, its diverse microbiome merits its contribution to the discussion on how future architecture can better accommodate inter-species relations (Grétarsdóttir and Hafsteinsson, 2020). The human metaorganism contains about as many microorganisms as we have cells (Abbott, 2016) which act as a permeable membrane to our environment, constantly communicating and exchanging with the microbiomes in our surroundings (Bosch *et al.*, 2024). In fact, Bosch et al. (2024, p. 1) warn that "evidence grows that contemporary built environments are steadily reducing the microbial diversity essential for human health, well-being, and resilience while accelerating the symptoms of human chronic diseases...". Learning from the turf house, buildings could take the form of intelligent membranes that protect us from human pathogens but provide the microbial biodiversity we need (Bosch *et al.*, 2024).

This project challenges anthropocentric paradigms by re-situating architecture as a medium for perceiving and interpreting multispecies interdependence. Through immersive engagement with the microbiome of Icelandic turf houses, it reframes the built environment as a living archive of ecological relationships—foregrounding microbial life not as metaphor, but as an active participant in shaping how we understand cohabitation. Rather than proposing new architectural forms, the project acts as a speculative interface that reveals the hidden ecologies embedded within vernacular structures, contributing to an expanded understanding of architecture as a host of more-than-human entanglements.

BACKGROUND

Of the various sites visited during field work, Keldur at Rangárvellir (see Figure 1) is the oldest remaining farmhouse, dating from 12th century and remaining inhabited until 1946, when it was acquired by the National Museum (National Museum of Iceland, no date). The farmhouse complex is made up of multiple buildings and sits on a meander of the Keldur brook, overlooking the valley at the foot of the Þríhyrningur mountains. At this location, we captured point cloud data with a terrestrial laser scanner (Riegl VZ-400i), which is mainly used in surveying and architecture. It has a range of 800m, receives GNSS signals, captures colour information with a camera attachment, and uses geo-referencing to facilitate scanning larger sites.

Figure 1. Impression of Keldur turf house arrangements. (Image credit: Aurora Navarro Villacampa, Aalto University.)

After the initial processing of the point cloud data, .LAS files were modified in Houdini to reduce point count to a manageable volume and to crop the areas of interest. The resulting .PCACHE files were then imported into Unity and displayed using a VFX Graph (see Figure 2). Unity is an industry standard game engine with a direct pipeline to the Meta Quest 2 virtual reality headset, which will be used for the development of this project. It's a reliable program with which to develop for VR, build interactive environments and then publish the resulting immersive experience.

Context within existing work

Due to its transdisciplinary nature, this project builds upon work in various fields, such as art installations in the field of ecology and VR experiences for architectural heritage digitisation.

Breathing with the Forest (2023) is a digital art piece commissioned by Emergency Magazine and created by Marshmallow Laser Feast. Similarly, Breathing with the Forest also uses point cloud LIDAR scans and field recordings, and later visualises hidden flows through visual effects. This project builds on top of that foundation, but presents spatial data as an explorable virtual environment, providing the visitor more agency in how they engage with the narrative. Visual effects and sound are dynamic, correlated to the data and responding to visitor interactions. According to Han et al. (2024), meaningful interactions are an important component in building an emotional connection with actors in the experience, contributing to a more immersive experience and a stronger post-experience effect.

There are multiple projects digitising architectural heritage, such as Google's Open Heritage (no date), the University of Cape Town's Zamani Project (no date) or Aalto University's Systems of Representation research group (no date). Google offers the possibility to explore their archive of 3D models in augmented reality, whereas Systems of Representation creates virtual reality experiences with an educational approach, intended for museum contexts. This project contributes to preservation efforts by documenting and introducing the turf house tradition to a wider audience, outside of the Icelandic context. However, achieving a high level of fidelity to reality isn't the aim and spatial data

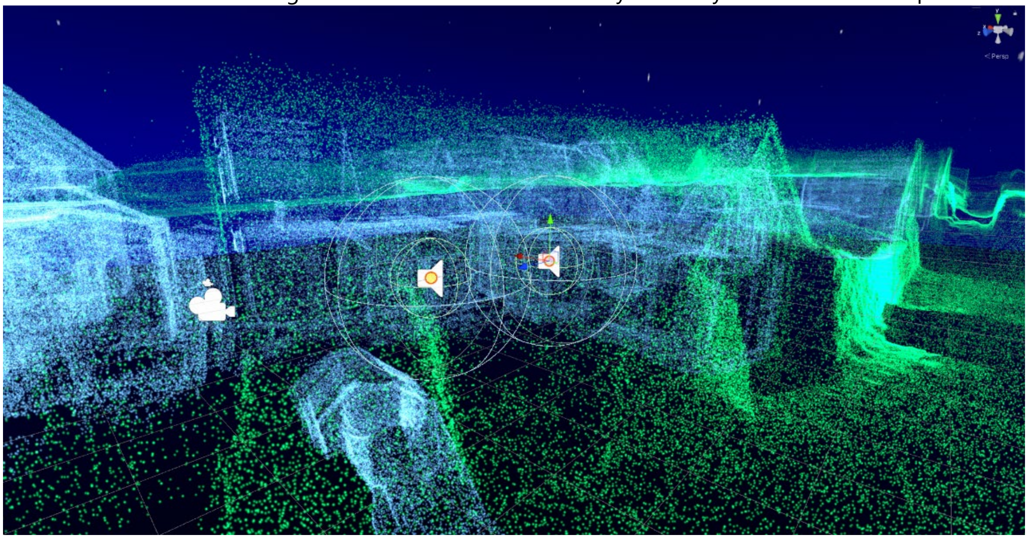

Figure 2.
Point cloud scans of Keldur turf house in Unity. (Image credit: Aurora Navarro Villacampa, Aalto University.)

is used mainly to contextualise and stage the narrative as more artistic liberties are taken in the additional visual design elements.

METHODOLOGY & DATA PROCESSING

Data processing

Tinna Grétarsdóttir & Sigurjón Baldur Hafsteinsson of the Turfiction project have been collecting samples at various locations (Grétarsdóttir and Hafsteinsson, no date). These samples were then analysed using RNA sequencing to identify the species present and their relative populations. Two datasets were produced, lists of eukaryotes and bacteria respectively. RNA molecules change from cell to cell, unlike DNA, and can be influenced by many factors such as environmental conditions or organism metabolism (Nova, 2025). Therefore, further analysis of the data could reveal detailed information on the processes conducted by each cell sampled, be it a bacterial or eukaryotic organism. This would give us a more clear idea of their role in the ecosystem and in the cycles of matter.

Discussions with various experts in the fields of anthropology, ecology and microbiology revealed that the abundance of an organism in an ecosystem does not make it important. Keystone species are of vital importance to their communities – they foment biodiversity and keep the ecosystem in balance (Chapin, Matson and Vitousek, 2011, p. 324). These keystone species were selected from the data as protagonists for the narrative, as it is more relevant to focus on their stories and impact than to show overall biodiversity, which was all that could be derived from the data after the first round of analysis. We researched the role of these keystone species in the ecosystem through their metabolisms, the processes by which they transform compounds and engage in the cycles of matter at a global scale. For example, without nitrifying bacteria, plants can't use atmospheric nitrogen but fixed nitrogen is essential for plant growth (Wang *et al.*, 2024), making them by extension essential for life on Earth. These processes were documented in a database by abstracting the transformation of matter as "input" and "output" compounds (see Figure 3).

This allowed us to create a network, connecting organisms through the compounds they transform – for example, Mycobacterium vaccae (phylum Actinobacteria) fix nitrogen as nitrates, which is then used by Vicia cracca (plant in the legume family) in order to grow. Therefore, NO3- (nitrates) acts as a connection between the two organisms – following the nitrogen compounds would allow us to eventually trace a closed circle, completing the nitrogen cycle. Represented through data sonification and visual effects, these flows of matter reveal the ceaseless activity that happens beyond our perception and yet we are very much a part of.

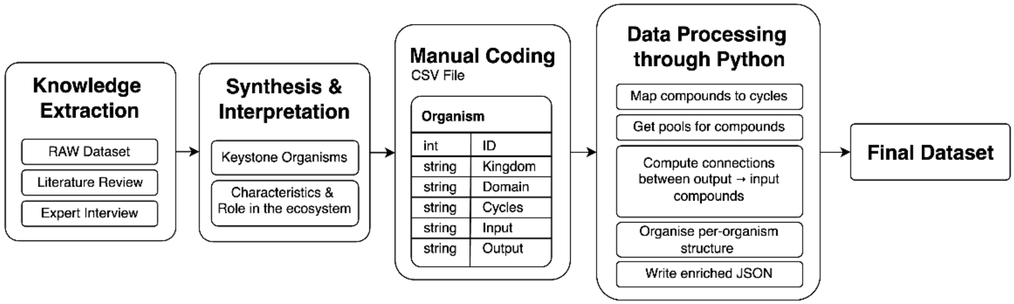

Figure 3. Diagram of steps taken in data processing. (Image credit: Eduard Tampu, Aalto University.)

As discussed by Chapin et al. (2011, p. 5), in the field of terrestrial ecology, an ecosystem is defined as consisting "of all the organisms & abiotic pools in which they interact". Biotic pools include living organisms such as plants, animals and soil microbes, and abiotic pools consist of soils, rocks, water and atmosphere. Loosely mirroring this logic, in the original dataset, samples were categorized as "air", "surface" or "core" based on the location from which they were extracted, as differences based on their respective environmental conditions were expected. When listing the chemical compounds exchanged by the organisms, it also became apparent that certain compounds were mainly found in certain pools – for example, nitrogen as a gas (N_2) is mainly found in the atmosphere and enters the biomass or soil as fixed nitrogen instead (NO_3^-, NH_4^+ or NO_2^-) (see Figure 4).

Data sonification

In this interactive experience, viewers can follow the compounds connecting different organisms, experiencing the transformation of matter through sound. To facilitate an understanding of these processes through auditory mediation, each organism's sonic characteristics are defined by three primary aspects: input and output compounds, the associated cycle of matter, and its classification within a biotic or abiotic pool.

Each compound corresponds to a specific set of musical degrees (in music, degrees are used to identify notes inside a scale (Piston, 1941), designed to reflect the molecules' complexity. Simple molecules are mapped to a few notes in lower octaves, while more complex structures are mapped through richer chords layered over multiple octaves. Harmonic relationships between different compounds are realised by using shared root notes for structures of similar composition. Timbral variation is introduced based on the compound's associated cycle of matter, thus enhancing differentiation and clarity. This approach allows the listener to perceive how the organism processes different substances, as input and output compounds are sonified using distinct instrumental colours associated with their respective cycles—carbon, nitrogen, water, or oxygen. Consequently, organisms involved in multiple cycles emerge with rich and layered sonic identities.

Lastly, the biotic and abiotic pools define the macro identity of the sonic environment. Each of the three pools acts upon (1) background sound elements, (2) spatial perception and (3) timbral layering. Thus, the user follows a processed compound from one organism to the other through a specific pool, which strongly impacts the way matter's transformations are perceived and understood. Alongside the previously mentioned processes, by sonifying the pools the aim is to convey how matter changes state through the action of these organisms.

The visitor can hear the difference between organisms by their functions, for example: nitrifying bacteria have similar sound identities as

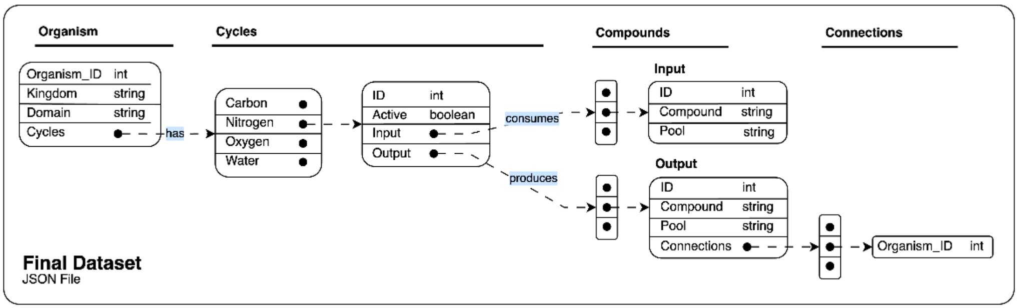

Figure 4. Visual representation of the dataset structure. (Image credit: Eduard Tampu, Aalto University.)

they are found in soil, taking in nitrogen gas and putting out a form of fixed nitrogen. Saprotrophs (decomposers) are also found in soil, granting them a similar macro identity, but they take in soil carbon and output carbon dioxide therefore the difference in compounds present is reflected in the change of notes, timbre & instrument.

The realisation of this sonification practice is achieved with two programs: Max/MSP (Max), which interprets the information and Ableton Live (Ableton), which produces the final sonic result. The user interaction is received by Max through an Open Sound Control (OSC) message, interpreted by a JavaScript (js) code, which produces all the necessary information for the sonification to happen: notes, durations and other control values. The computational process undergoing inside the js code follows four main stages: (1) load and prepare the dataset, (2) interpret the user interaction, (3) create data packs linked to the received interaction, and (4) produce the notes, time structure and control values (see Figure 5). Inside Ableton, this information is received and used for controlling the synthesis models and parameters such as gains, signal processing parameters and spatial behaviour of the sources.

IMMERSIVE EXPERIENCE OF DATA-DRIVEN NARRATIVES

Han et al. (2024, p. 363) define immersive experiences as “the acceptance of one’s involvement in the moment that is conceived through multiple senses, creating fluent and uninterrupted physical, mental, and/or emotional engagements with a present experience, with the ability to attain a lasting mental and emotional effect on the user’s post-experience”.

A deeper sense of immersion can be achieved through multisensory engagement by further detaching the user from the physical world (Han, Melissen and Haggis-Burridge, 2024), hence the importance in this project of the visual, audio and spatial elements. The sound elements largely support the immersion into the microbial world as one of the key narrative elements, conveying different information than what is being shown visually.

Figure 6 shows the point cloud environment built in the Unity game engine. Based on the user’s proximity to the organism, two colliders act as spatial triggers. When Collider A1 is crossed, the user can begin to hear the organism’s layered sonic identity building gradually. When Collider A2 is crossed, the organism and its connections to others become visible through visual effects, which serve to distinguish different organisms. The Paths now visible guide the user in their spatial exploration of the network, showing the organisms’ interconnectedness due to the compounds they exchange. Following the Paths, the user can hear a different sonic identity as they cross Collider B1, indicating the transformation of matter.

Introducing the sound first allows us to shift the user’s attention to the spatial context and the sound itself as it builds in complexity. This is followed up with the visual effects, which give a

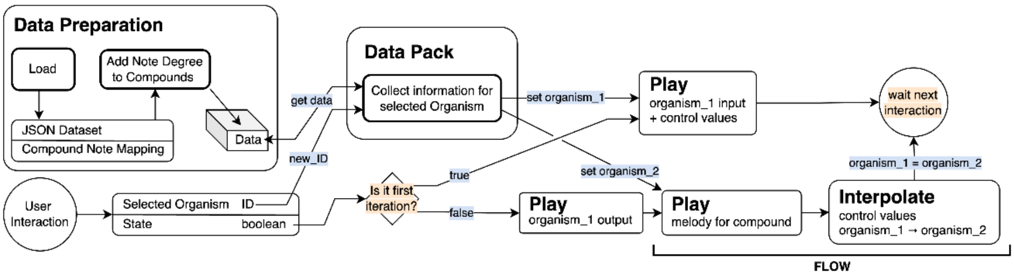

Figure 5.
Diagram showing data sonification system responding to user interaction. (Image credit: Eduard Tampu, Aalto University.)

"face" to the protagonists of the narrative, serve as an anchor for additional information and guide the next steps in the experience.

The project introduces a framework for engaging with ecological processes that are typically inaccessible through conventional design methods, foregrounding processes, relationships and transformations that are otherwise difficult to sense. Rather than proposing new architectural forms, it expands the scope of architectural inquiry by using immersive, data-driven tools to render microbial and biochemical dynamics perceptible and experientially meaningful (Zhou, 2023)l.

In its narrative and interactive concept, this project synthesises information from various disciplines, emphasising the areas where they overlap. This transdisciplinary approach makes the complexity two-fold, as it is not only essential to understand the relevance of each individual topic but also their significance to one another. For this purpose, an immersive experience grants us a range of elements through which to gradually present different information, in different forms, to the user. The virtual environment acts as a transdisciplinary interface, enabling users to explore architecture as a mediator of multispecies entanglements and supporting an expanded spatial literacy that is grounded in ecological complexity and more-than-human interaction. Partnered with immersion, the lack of disruptions creates an increased sense of presence, allowing the user to focus on learning, information retention and processing (Han, Melissen and Haggis-Burridge, 2024). This format offers the user agency in exploring the information and virtual space in a non-linear way, adaptable to different interests, profiles and needs of a wider audience.

The project contributes not only to public understanding but also to architectural discourse by suggesting that immersive, narrative-driven environments can serve as a mode of ecological engagement. It positions architecture not as a fixed construct, but as a perceptual framework, capable of translating the invisible operations of living systems into spatial experience and shared knowledge (Fricker, 2024). According to Han,

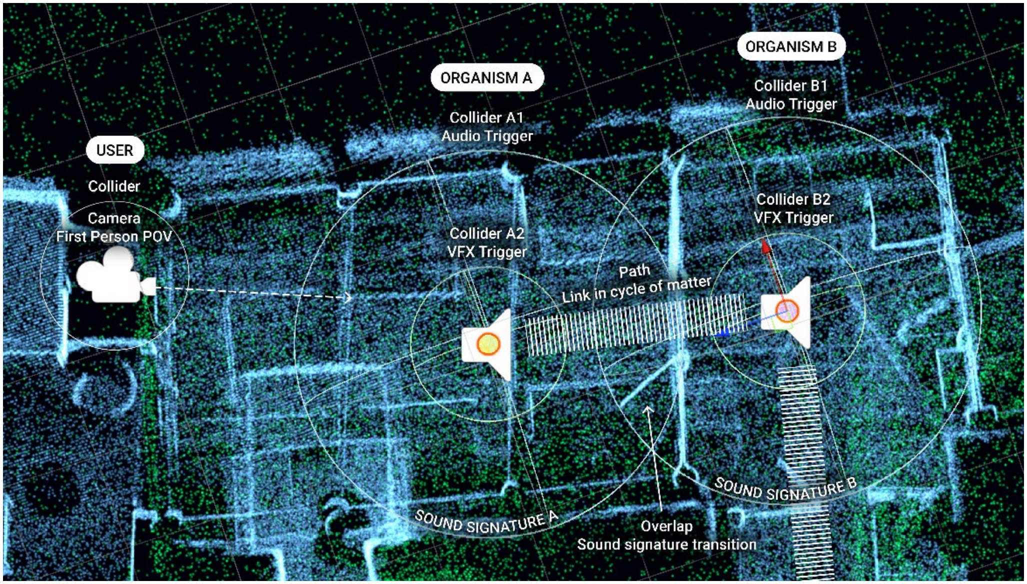

Figure 6. Screenshot from Unity's editor showing the interactive elements of the VR experience. (Image credit: Aurora Navarro Villacampa, Aalto University.)

Melissen and Haggis-Burridge (2024), immersive experiences can have a deep effect on the user's mental and emotional state, which can in turn stimulate long-lasting changes in attitude and behaviour post-experience. Affecting public perception by shifting perspectives on the importance of the microbiome in our (built) environment and its direct impact on the human meta-organism can be instrumental in eventually catalysing change at a larger scale.

DISCUSSION

This project is developed as a focused prototype to explore the educational potential of translating microbiome data into an immersive experience. Given the complexity of the subject, the current version emphasizes clarity and coherence rather than presenting all possible layers of information. Including additional content, such as data on microbial metabolisms, could further enhance the depth of the experience and increase its relevance in educational contexts. At the time of development, the dataset is limited to population numbers identified through RNA sequencing. The inclusion of metabolic data from the outset would simplify processing and allow for a more detailed representation of microbial activity.

CONCLUSION & OUTLOOK

This project constructs an immersive, interactive experience using multisensory stimulation and spatial exploration to communicate transdisciplinary, data-driven narratives rooted in ecological processes. By integrating microbiological data with point cloud scans of vernacular Icelandic turf houses, the project repositions the architectural environment as an interface through which complex, more-than-human systems become perceptible and experientially accessible.

The use of spatial representation, via both visual and sonic modalities, not only serves as a means of storytelling, but as a speculative tool for expanding architectural inquiry (Fricker, 2023).

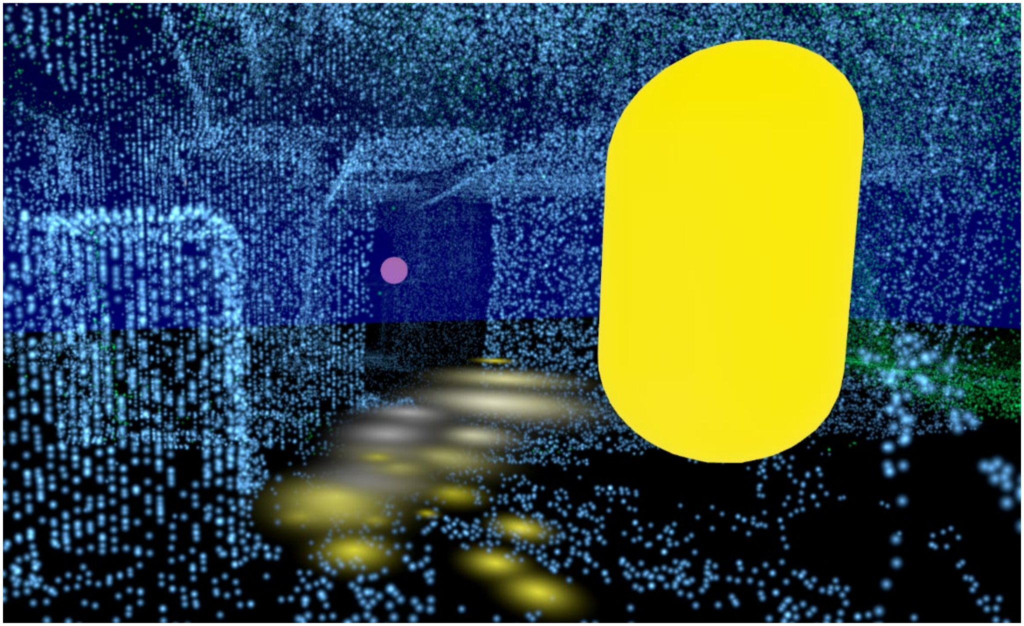

Figure 7. Screenshot from Unity of the user perspective while wearing the VR headset. (Image credit: Aurora Navarro Villacampa).

Rather than generating new architectural forms, the project leverages immersive media to foreground architecture's capacity to mediate between human and microbial scales, drawing attention to the biochemical flows and ecological entanglements embedded within historical building practices.

Through its methodological synthesis, combining site-based documentation, ecological data, and real-time interaction, the project offers a model for how architectural environments can function as living, responsive systems. The virtual setting acts not as a simulation of heritage, but as a transdisciplinary framework in which spatial, biological, and perceptual logics intersect.

In doing so, it proposes a shift in architectural thinking: from form and function toward process, metabolism, and relationality. The resulting VR experience invites a reconsideration of how architecture participates in larger ecosystems, not only as shelter or symbol, but as an active membrane in cycles of matter and meaning. While grounded in digital tools, this perspective repositions architecture as a lens for exploring material, situated, and inhabited relationships, offering expanded modes of ecological engagement (Fricker, 2025). In doing so, it frames architectural space as a structured medium for observing and interpreting environmental processes, enabling new forms of spatial inquiry into more-than-human dynamics.

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