Designing Multisensory Biophilic Futures: Exploring the Potential of Interaction Design to Deepen Human Connections With Nature in Indoor Environments

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Figure 1: Examples of biophilic architecture: (a) An Indian temple that cyclically floods from a nearby river as a symbolic connection to cleansing of the site and the "soul". Image credit: Sriharsha, 2018. Accessed May 14, 2025. (b) Frank Lyold Wrights's iconic Fallingwater house that was designed to look like it is emerging from a waterfall. Image credit: Pixabay, 2016. Accessed May 14, 2025.

Abstract

Advances in interaction design, architecture, and artificial intelligence offer new possibilities for built environments. Yet, most systems focus on improving physical parameters such as indoor air quality. While these enhance physical comfort, they often overlook an innate aspect of human experience—our connection with nature—fundamental to physical and mental health. In contrast, architecture offers a rich legacy of biophilic design that creates sensory-rich spaces evoking a connection to nature. What insights can biophilic architecture offer to guide interactive experiences in future buildings? Drawing on 13 expert interviews, we expose the gap between current biophilic practices in smart buildings and the multidimensional potential of nature-inspired design. We present eight themes reflecting expert imaginaries of biophilic futures and five design opportunities illustrating how emerging technologies can position biophilic interaction as multi-sensory, interpretive, and aligned with more-than-human, justice-oriented futures.

CCS Concepts

• **Human-centered computing** → **Human computer interaction (HCI)**; **Interaction design**; **Interaction design theory, concepts and paradigms**;

Keywords

biophilic design, multisensory, smart buildings, nature interactions, multi-species, semi-structured interviews, more-than-human

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1 Introduction

Interactive systems are integral to building design, leveraging advances in sensing, actuation, and data processing to regulate parameters such as lighting, temperature, and air quality [2]. These systems enhance comfort, energy efficiency, and sustainability while adapting spatial layouts to create private or collaborative spaces within shared environments [34, 94, 95]. However, this approach often embodies an anthropocentric and technocentric paradigm [46], treating buildings—and the technologies within them—as functional spaces optimised for productivity [53]. This perspective neglects the potential to enrich deeper, experiential dimensions, such as those rooted in our innate connection to nature [66, 68, 133].

Biophilia refers to the intrinsic human tendency to seek connections with nature and other forms of life [133]. Biophilic design builds on this, advocating for the integration of natural elements, patterns, and processes into the built environment to support meaningful connections with nature. This approach is grounded in a growing body of evidence demonstrating that a biophilic connection yields psychological and physiological benefits, including stress reduction, cognitive restoration, and enhanced creativity [43, 51].

In architectural legacy, biophilia is deeply embedded. Traditional methods have employed natural materials and site-sensitive layouts to promote ecological awareness, sensory engagement, and emotional connection [18, 66]. For instance, an ancient Indian temple at a river's origin cyclically submerges during monsoon season, symbolising purification and renewal—of both the building and the soul—while reinforcing human-ecological ties [45]. Similarly, Frank Lloyd Wright's Fallingwater in Pennsylvania exemplifies this, blending the built form with the surrounding waterfall[1].

Despite this legacy, biophilic design remains underutilised in smart building technologies, which rarely explore how interactive systems might foster deeper, multisensory relationships with nature. There is a need to integrate biophilic principles into smart building research, towards environments that are not only advanced but also ecologically and experientially rich. Human-Building Interaction (HBI), which explores technologies, spaces, and subjective experiences [1, 10, 101], offers a promising context for this integration. By acknowledging emotional, cultural, and sensory dimensions, HBI can support environments that promote well-being, nature-connectedness, and sustainability for "human flourishing" [85].

This paper explores the following question: *What insights can be drawn from the legacy, practice, and imaginaries of biophilic architecture to guide the design of interactive experiences in future buildings?* Through interviews with 13 architecture experts, we investigate the potential of biophilic design within the context of current and future smart buildings. We acknowledge biophilic design as a reciprocal practice benefiting both humans and nature, though current discourse remains largely human-centred; our perspective focuses on expert insights rather than normative prescriptions.

Our analysis reveals a gap in current practices and the possibilities of nature-connected interactions in buildings. We present *seven high-level topics (TO1–TO7)* that offer a structured overview of expert discourse, followed by *eight themes (T1–T8)* that capture how professionals imagine the future of biophilic design. These themes provide a conceptual foundation for nature-inspired interactions in indoor spaces. Next, we introduce *five design opportunities (DO1–DO5)* supported by emerging technologies to enable novel biophilic interactions. By bridging architectural biophilia with interactive technologies, we expand the discourse on smart buildings—reimagining how nature can be integrated into indoor experiences and reorienting biophilic interaction as reciprocal and aligned with more-than-human, justice-oriented futures.

2 Background and Related Work

We first review biophilic design in architecture, then examine its treatment in HCI and Interaction Design (IxD), highlighting gaps and situating this work within these fields.

2.1 Biophilia and Its Treatment in Architecture

Edward Wilson popularised biophilia as humanity's evolutionary need to connect with nature, an "innate tendency to focus on life and lifelike processes"[133]. This connection extends beyond physical contact, encompassing emotional, cognitive, and ecological awareness[124]. A greater interaction with nature strengthens this connectedness, and those with stronger connections actively seek more nature-oriented experiences [124].

Architecture has long reflected this interdependence between humans and natural environments. Traditional Japanese tea houses, for instance, embody concepts like wabi-sabi, valuing authenticity, ageing, and transience, with designs that *extend into the surrounding landscape* [64]. However, modern industrialisation led to building practices increasingly detached from ecological context. In response, architects like Frank Lloyd Wright championed "organic architecture"[91], while Ian McHarg's *Design with Nature* promoted ecological integration[87]. Stephen Kellert later formalised biophilic design into a set of principles such as natural lighting, materiality, and biomimicry that could be embedded into human-centred design frameworks [68]. Today, biophilic design is being revisited as a response to climate change, urban stress, and declining nature connectedness. Initiatives like the Living Building Challenge[2] promote regenerative design through green roofs, vertical gardens, and water recycling. Contemporary examples include Singapore's Gardens by the Bay[3], Apple Park's ecologically integrated campus[4], and Maggie's Centres [117], which use natural light, greenery, and views to support healing and well-being.

2.2 Human-Nature Interaction in HCI

HCI has explored the intersection of technology, people, and nature through areas such as Human-Nature Interaction and Natural Interaction [55]. NatureCHI studies how people use technology in natural environments [50], and Outdoors HCI designs for wild or semi-wild spaces [62, 88] like gardens [105] and farms [79]. Recent reviews highlight strategies to enhance human-nature relationships through technology, including engaging with urban nature, bridging indoor-outdoor experiences, and supporting personal narratives [88, 114, 128]. While these approaches emphasise interaction

[1] https://fallingwater.org/

[2] https://living-future.org/lbc/

[3] https://www.gardensbythebay.com.sg/

[4] https://www.fosterandpartners.com/projects/apple-park

in natural settings, our work focuses on built environments. We explore how occupants can form intrinsic, multisensory connections to nature indoors, using biophilic design to reimagine how smart buildings support nature-connected experiences.

2.3 Biophilia in IxD for Indoor Built Environments

Biophilic interaction design (IxD) in indoor environments typically focuses on fostering (a) connection to nature, (b) restorative experiences, and (c) ecological awareness [102]. Designs aiming to establish **nature-connection** often tend to keep the nature of the "connection" broad. Digital "windows" simulate outdoor landscapes to foster a sense of connection with nature [38, 126]. Soft robotic flowers evoke playful, memory-rich interactions [27, 86], while nature-inspired wallpapers use dynamic lighting and touch-activated soundscapes to extend these sensory links [20].

Restorative systems replicate nature's psychological and physiological benefits, especially in spaces where direct access is limited [83, 96]. For instance, plant-like movements (i.e. responding to plant-generated electrical signals) and surfaces with cellular structure patterns were explored in confined spaces for restoration [107]. *Nature Jar* uses digital metaphors of growth to encourage mindfulness and restoration [127]. Other works remind people to take breaks through nature-inspired technologies, directing their minds toward nature as a means of relaxation [63]. Generative art has also been used to create biophilic displays, offering evolving visuals for stress relief [135]. Immersive experiences, such as *Virtual Nature*, leverage virtual reality (VR) to simulate restorative natural environments.

To promote **ecological awareness**, some designs embed nature-inspired cues into daily life. For example, sensor-embedded plants nudge users into taking stairs instead of elevators, saving energy [80]. Wearable devices like *FloraWear*, offer tactile, mossy surfaces, to signal nature interdependence [92]. Playful digital games have also explored biophilic design for promoting pro-environmental behaviour in the built environment among children [33].

2.3.1 Sensory Modalities in Biophilic Design. Biophilic design aims to evoke feelings of being in nature through multisensory engagement. Visual elements like projected greenery or simulated natural lighting are widely used to evoke feelings of being in nature [5, 35, 136]. Auditory soundscapes mimicking birdsong or flowing water have been shown to enhance nature connectedness [5, 35, 136]. In contrast, modalities like touch, smell, and taste remain under-explored despite their immersive potential. Some works combine multiple senses. Touch and visual interactions were explored in *Nature-bot*, which comprised robotic flower-like displays made of different materials to encourage playful interactions [27, 86]. Similarly, *LiveNature* combined tactile sensations through wool (evoking contact with sheep) with ambient displays for connection to rural environments [38]. Few explore sensory integration: Living Wallpaper responds to touch with birdsong and motion-triggered fading prints [20], while one installation blended visuals, sound, and smells to evoke river landscapes [131].

2.4 Gaps and Positioning

We see that existing biophilic research in IxD often broadly focuses on fostering connections to nature or enabling experiences of restoration and ecological awareness. Much of this work is fragmented, with limited exploration of the diversity of human experiences with nature such as sensory engagement, ecological interdependence, and cultural narratives [125].

This paper draws on architectural perspectives to surface expert imaginaries and explore new possibilities for biophilic interaction in smart environments. Rather than offering precise definitions of biophilia or prescriptive technology design guidelines, we foreground conceptual and speculative insights rooted in biophilic architecture. Our goal is to broaden the discourse on biophilic interactivity in smart buildings across HCI, architecture, and IxD, and to lay a foundation for future empirical studies and design explorations.

3 Methodology

This section outlines the research methodology used to investigate expert insights on biophilic design, detailing the interview design, participant selection, and data analysis approach.

3.1 Expert Interviews

We conducted semi-structured interviews, chosen for their flexibility to explore experts' unique insights while maintaining a consistent structure across sessions [12]. A prepared "interview guide" outlined core areas of discussion with open-ended questions to encourage experts to be reflective and forward-thinking, while providing flexibility to tailor the conversations to their expertise. The conversations were organic, primarily driven by the experts' insights, with the guide serving as a loose framework to ensure relevance and depth, rather than dictating the flow of discussion. Ethical approval was obtained from the institutional review board. All experts provided verbal and written consent. Interviews were conducted in person or online, lasting 60–75 minutes.

3.1.1 Interview Design. Conversations were loosely structured around experts' context, grounded insights, experiential perspectives, and visionary outlooks—balancing practical inquiry with speculative thinking. **Context-setting** focused on situating experts within the framework of biophilic design while exploring their interpretations of its philosophy and its relevance within smart environments. **Grounded insights** explored practical design and engineering considerations, financial restrictions, technical challenges, and limitations. At this point, experts were invited to share their insights on opportunities for incorporating the different sensory dimensions to foster immersive connections to nature. **Experiential perspectives** drew on personal stories and case studies where nature-inspired design created profound connections. Finally, **visionary outlooks** invited experts to imagine future biophilic spaces that respond to emerging human and ecological needs.

3.2 Selection of Interviewees

Experts were recruited via email through purposive sampling [110]. We reached out to individuals with significant contributions to biophilic design and related fields, including those affiliated with

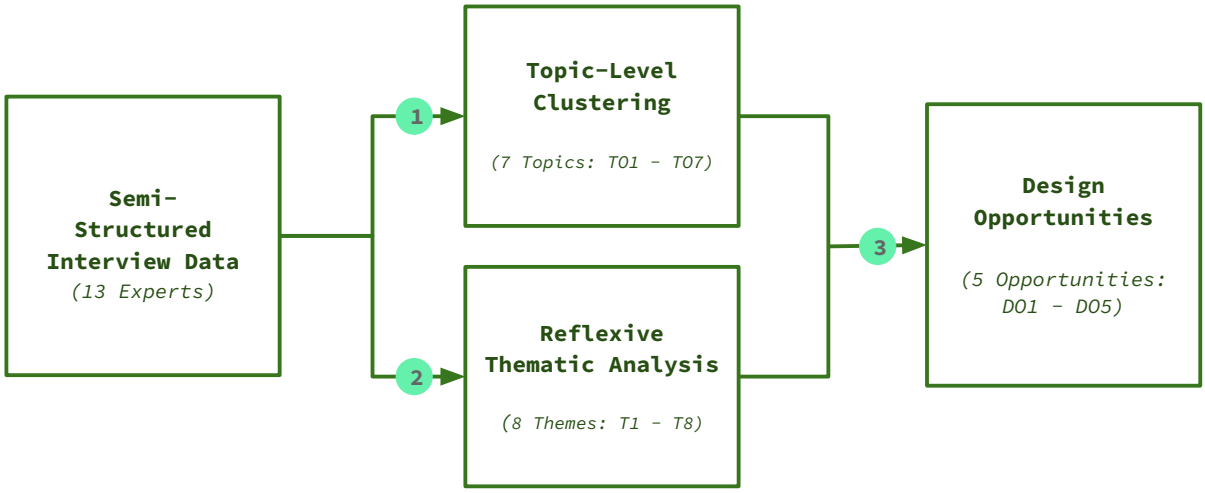

Figure 2: An overview of our data analysis process. First, we conducted topic-level clustering of interview responses, identifying seven descriptive topics based on recurring ideas across the interview questions. Next, we carried out a reflexive thematic analysis of the full dataset to generate eight themes. Finally, based on the topics and themes, we interpretively synthesised five design opportunities to support research on biophilic interaction in smart buildings.

leading, global architecture firms, high profile architecture and design projects, as well as distinguished academic contributions. As the interviews progressed, snowball sampling was employed, leveraging existing experts' networks to identify additional experts [103]. In this way, we invited *25* experts of which *13* participated. Among them, 8 were industry experts, including lead architects and senior designers (urban and landscape), while 5 were from academic backgrounds, comprising researchers specialising in interactive architecture and environmental psychology. A summary of participant demographics along with their stated expertise in biophilic design is provided in Appendix B.

3.3 Data Processing and Analysis

We conducted 13 expert interviews, resulting in approximately 17 hours of recorded audio, which were transcribed and analysed through a multi-stage process. Our analysis yielded findings at three levels: (1) topics summarising the interview data, (2) reflexively constructed themes around expert imaginaries in biophilic design, and (3) design opportunities. Figure 2 summarises this process.

3.3.1 Step 1 – Topic-Level Clustering of Expert Responses. We began by organising the interview data using the structure of our interview questions (c.f. subsection A.1 and discussed under Interview Design). We then grouped similar responses and identified recurring ideas. From these patterns, we developed a structured coding scheme (Figure 3) comprising high-level topics such as *values*, *deeper connection*, and *technology*. These topics summarise expert discourse and surface the breadth of insights across the interviews, reflecting a high-level, descriptive structuring of the dataset.

3.3.2 Step 2 - Reflexive Thematic Analysis. Next, to elicit deeper insights from the dataset, we conducted a bottom-up reflexive thematic analysis following Braun et al. [16], Byrne [22], which allowed for an iterative and open coding process. Reflexive thematic analysis was chosen for its effectiveness in identifying and interpreting patterns across datasets, particularly in under-researched areas [17, 30]. This analysis was conducted independently of Step 1, where we returned to the full dataset and carried out line-by-line coding of the transcripts. Each sentence was examined with attention to both semantic and latent meaning, yielding 471 open codes (e.g. *"spirit of the place"*, *"participatory stewardship of nature"*, *"biophilic design as corporate culture"*). These codes were iteratively reviewed and refined to create themes that reflect the possibilities of biophilic design, as articulated by the experts.

3.3.3 Step 3 – Deriving Design Opportunities. Finally, we engaged in an interpretive synthesis to develop design opportunities for interaction design in smart environments. This process drew from the structured topics (Step 1) and reflexive themes (Step 2), re-examining the findings through our designerly and technological lens. For each opportunity, we also proposed speculative technology examples using "what if?" scenarios to explore how biophilic interaction might be reimagined.

Throughout the study, the first and last author discussed and resolved methodological and analytical decisions. The first author identified high-level topics based on the transcripts, which were then reviewed and refined (Step 1). The first author then conducted open coding and theme development, with codes and developed themes discussed and adjusted in joint meetings (Step 2). Finally, the first and the last author iteratively reviewed and shaped the design opportunities (Step 3).

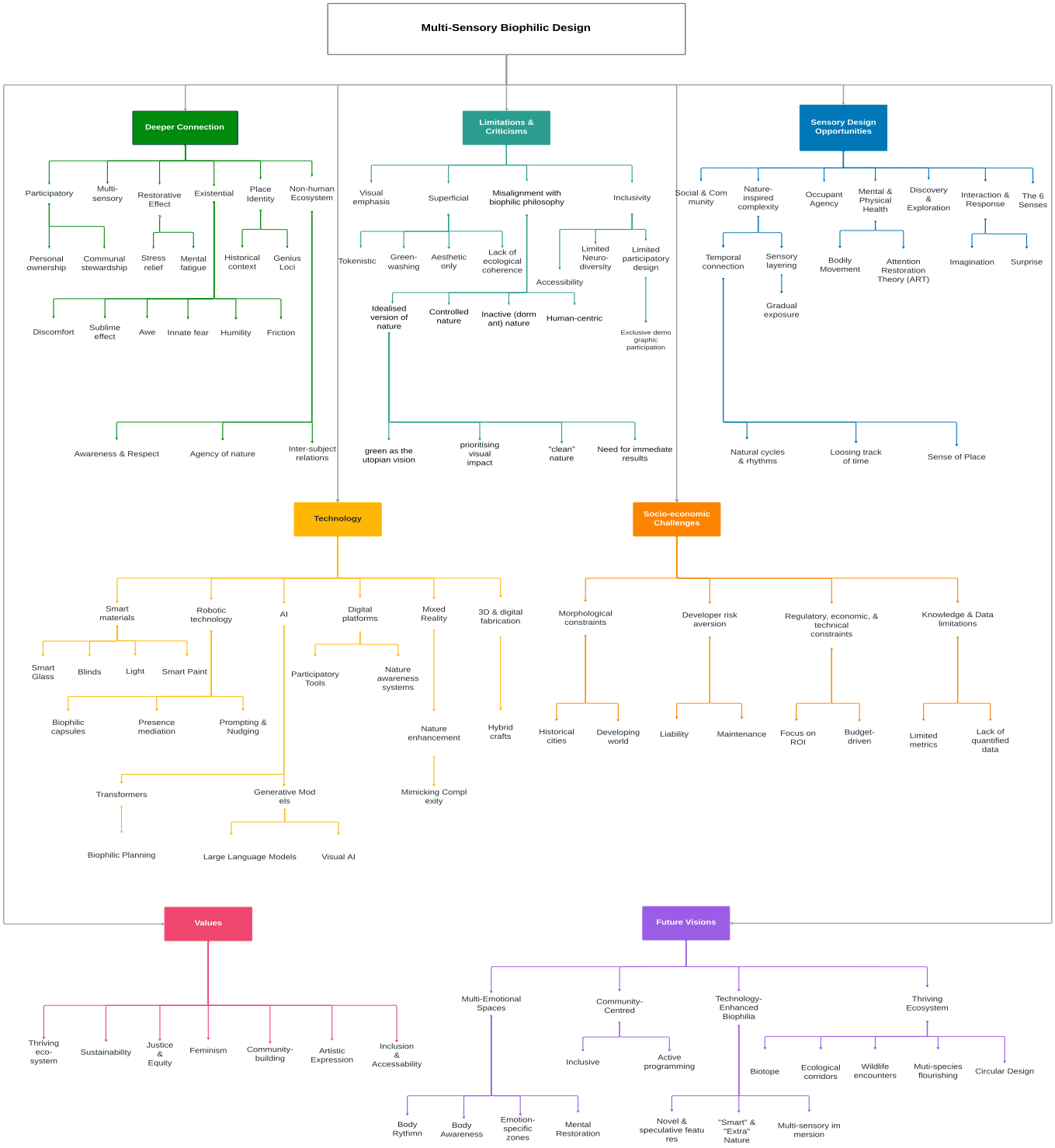

Figure 3: The structured coding scheme developed during Step 1 of the analysis to provide an overview of the discussions. Based on the interview structure, this scheme clusters recurring insights into seven topics that represent expert perspectives on multisensory biophilic design in indoor environments. Each topic contains subtopics and concepts discussed by experts.

4 Findings: Topic-Level Clustering of Expert Responses

This section presents the seven topics (TO1–TO7) derived from our topic-level clustering of expert interviews, offering a descriptive overview of how experts conceptualise biophilic design in smart buildings. An overview of the seven topics and their relationships is provided in Figure 3.

TO1 - A Deeper Connection to Nature: Experts spoke of designing for a "deeper connection to nature" in indoor spaces as a core philosophy underpinning biophilic design [67]. Beyond evident health benefits, they suggested that deeper connections could be fostered through existential moments of awe and humility, shifting perspectives from controlling nature to reflecting on humanity's place within it. Experts stressed the importance of designing spaces that celebrate ecological uniqueness, recognise nature as an active agent in fostering respect, and encourage participatory care for natural spaces. They also highlighted integrating non-human ecosystems, such as pollinator habitats, into human environments to shape behaviour, foster biodiversity appreciation, and challenge cultural assumptions that separate humans from nature.

TO2 - Limitations and Criticisms: Experts criticised reliance on visual perception as the primary sensory dimension for design. While impactful and accessible, this overemphasis neglects opportunities to create more immersive multi-sensory experiences. Additionally, experts pointed out the dilution of biophilic philosophy over time through superficial approaches such as the use of fake plants that prioritise aesthetics over authenticity and fail to reflect natural processes. A lack of ecological coherence was also discussed, with many designs featuring token, isolated elements that fail to provide ecological continuity with the surrounding spaces.

TO3 - Sensory Design Opportunities: Experts highlighted the underutilisation of smell, sound, and taste in biophilic design. Smell, despite its emotional and memory-triggering capabilities [54], is often avoided due to concerns about undesirable natural odours. Sound practices focus on noise reduction (also pointed out by Spence [113] in his work summarising multisensory design) rather than leveraging natural auditory elements like birdsong to enrich sensory experiences. Taste is rarely addressed, limiting its potential in specific, niche contexts (e.g. [59]). Experts also spoke of opportunities for biophilic spaces that respond to human movement to enhance users' sense of self and foster stronger connections to their environment. Multi-sensory designs that facilitate meditation, immersion, and exploration of nature's systems (e.g. microbial systems [104]) can provoke curiosity.

TO4 - Technology: Experts put forth the notion of "smart nature" or "extra nature", considering technology as a design material for biophilic experiences in architectural spaces. In addition to climate-responsive innovations like hydro-gel windows that regulate sunlight for occupant comfort [139], they proposed technology such as *reactive biophilic booths*, retrofitted with lighting, air quality, and sound sensors, as a modern extension of sun-bathing booths to provide intense, immersive nature-inspired experiences. Experts also discussed leveraging relatively "low-fi" technology such as QR codes and mobile applications as digital cues to prompt interaction with natural elements. Generative AI was highlighted for its potential to create innovative visual biophilic designs [108, 135], while Mixed Reality (MR) technologies were suggested for their ability to blur artificial and natural environments.

TO5 - Socio-Economic Challenges: Experts surfaced regulatory, economic, and technical constraints that limit the extent to which biophilic design is implemented in indoor spaces. Reliance on nurseries for specific plant species can pose logistical challenges, while project tender processes often prioritise cost efficiency, stifling opportunities for creative and sustainable solutions. In heritage areas, strict preservation laws and morphological constraints complicate efforts to balance cultural preservation with ecological improvements. Experts also highlighted trade-offs in urban environments where vertical expansion is favoured, compromising ground-level connectivity and ecological continuity.

TO6 - Biophilic Design Values: Experts discussed the importance of embedding societal values such as neurodiversity [19], feminism [14], and community justice [40] into biophilic design for indoor spaces. They also highlighted the need for these environments to cater to marginalised and transient communities that can benefit from nature connectedness for emotional and physical healing. Artistic expression through storytelling and spatial design was identified as a means to reflect community identity (as done by [109]). By integrating local narratives into natural spaces, biophilic design can strengthen cultural ties and foster deeper personal connections to nature. Experts also noted that collaborative approaches could empower communities to actively care for and sustain these environments.

TO7 - Speculative and Future Visions: Experts envisioned future biophilic design that can create integrated ecosystems within indoor spaces, such as biotopes and ecological corridors, to support building wildlife (previously discussed at a city scale [140]). These participatory ecosystems were seen as fostering species coexistence and offering novel experiences, including moments of discomfort to enrich nature interactions. They also proposed *emotional biophilic spaces* designed to adapt to body rhythms, emotional states, and gender-specific needs. This vision included incorporating natural rhythms, such as tides and seasonal changes, to evoke a sense of belonging to larger natural cycles. Experts also suggested leveraging natural light to create transparency and reflections, evoking concepts like infinite vistas and horizon views.

5 Findings: Thematic Analysis

We present eight themes (T1–T8) developed through a bottom-up reflexive thematic analysis [16, 22]. Each line of interview data was open-coded, with codes iteratively grouped into themes. We include illustrative quotes to ground each theme in expert insight and summarise them in Table 1.

T1 - Ecological Authenticity and the Essence of Nature in Building Design: Our analysis reveals the need to re-evaluate biophilic design philosophy [133] in contemporary building practices. Experts critiqued the superficial adoption of biophilic design and the tendency to treat nature as a static background (e.g. through use of artificial plants), reducing it to aesthetic elements devoid of

ecological interaction or ecological value. One expert noted: *"When nature is treated as an object, we miss the opportunity to learn from and collaborate with it, instead imposing our own limited understanding."* Others raised concerns about building rating systems like *WELL certifications*[5], arguing that they risk reducing biophilic design to checklists, inadvertently fostering "green-washing".

In exploring the essence of nature in building design, experts highlighted a non-interventionist mindset for achieving ecological authenticity (discussed further in section 6). The concept of "*third landscapes*" where *space expresses neither power nor submission to power...*", inspired by Clément et al. [31], was mentioned as a model for enabling ecological processes to emerge naturally—designing for conditions rather than dictating outcomes. One expert described this as: *"Instead of dictating (e.g. planting) designs, we should focus on creating foundational conditions like soil and shade to let nature respond and evolve."* These reflections raise questions about the role and representation of nature in design: What constitutes the essence of nature in built environments, and how can we reconcile its authenticity with the functional and experiential expectations of intelligent indoor spaces, while respecting its authenticity?

T2 - Art as an Expression for Biophilic Experiences: Biophilic art is well documented [15, 89] in HCI through examples such as robotic flowers [27] and vapour-based spatial partitions [34]. Experts highlighted (emerging) technology as an "artistic material for extending natural behaviours" and enabling participatory design approaches. Biophilic art must embody "response" to reflect nature's essence (tying to the previous theme of ecological authenticity): *"...An important layer is reaction, so whenever a human does something, the sensory nature experience reacts. So like grasses in a landscape where you run through with your hand, and then lights start to glow. It's not natural in the way we know it, but it would give, I think, a very natural response."* Experts suggested that this response could take the form of *soft fascination*—a quality that gently captures attention without overwhelming the mind (explored in HCI [8, 106])—creating moments of distraction or relief.

Digitally mediated biophilic art can act as a participatory medium, encouraging occupants to engage with and shape their surroundings, as well as develop emotional and cultural connections to nature: *"Artistic dimensions can mediate between human-made environments and natural inspirations, crafting spaces that resonate emotionally with users."* This could be through art that spatializes human interaction with nature (e.g. [81]), such as interactive projections or augmented reality experiences [111]. Studio Roosegaarde's *Waterlicht* installation, which uses light and reflective lenses to simulate virtually flooded environments[6], was shared as an example. Crafting and 3D printing were highlighted as another participatory medium for tying cultural narratives with nature. Iris van Herpen's *Architectonics* demonstrates coexistence between humans and aquatic environments through future floating cities fashion[7].

T3 - Biophilic Design for Ecological Empathy: Biophilic design holds the potential to foster ecological awareness and empathy in urbanised societies where disconnection from nature is growing [78, 127]. Experts described how interactions with nature influence values like kindness and respect, encouraging empathic behaviours. However, two limitations constrain current approaches.

First, raising awareness without cultivating a lasting commitment to ecological preservation is insufficient. Experts suggested integrating participatory stewardship, where individuals care for natural elements to build a sense of responsibility. Central to this is *"cues for care"* (previously put forth by Nassauer [93])—design that signals value and the need for maintenance. One expert described a project using QR codes and sensors to trigger pop-ups with information about nearby plants: *"We're adding a technical layer to inform people about what is happening there...At [company name], we wanted to create a sort of walking green route where once they're (employees) near a sensor, they get a pop-up about the plant or the tree so they can learn more about it..."*

Second, buildings fail to make invisible ecological processes like species health or inter-species interaction perceivable to occupants (e.g. the MicroAquarium installation that reveals live microorganism activity [76]). These interactions often unfold at temporal scales that are not perceptible to humans, making them harder to translate into meaningful interactions. Experts argued that making such processes visible can reinforce a sense of interconnection: *"By designing buildings that show people how to coexist with other species, we can remind users of their interconnectedness with the living world."* While indoor biotopes are a known strategy [69], experts felt they often prioritise aesthetics over fostering curiosity and reflection. Such an emphasis limits the ability to inspire empathy and a sustained commitment to preservation.

T4 - Multisensory and Multidimensional Biophilic Design: In literature, we found that visual elements like greenery, views, and patterns are common [9, 77]. This visual focus has been critiqued, notably by Pallasmaa in *The Eyes of the Skin*. Addressing this, one expert remarked: *"Using visual is an easier way to experience biophilia, and we found that most biophilic designs heavily relied on this sense."* While foundational, visual design alone fails to capture the full richness of how humans interact with nature. Experts stressed that nature inherently presents *layered* sensory experiences, such as visual, auditory, tactile, and olfactory, creating interactions that are often absent indoors. The kinaesthetic sense—our awareness of bodily movement—was emphasised. Experts spoke of designing for kinaesthetic sense in two ways: *movement (with)in nature* (e.g. flowing water, shifting light) and *movement towards nature* (e.g. spatial layouts that invite exploration). One shared: *"It's not enough to see trees through a window—design should invite people to go out, move, and interact with the environment."*

Experts described biophilic experiences as multidimensional, offering three key experiential examples: First, nature operates on varying *scales*, from the vastness of landscapes that inspire awe and reflection, to the intimacy of small details that invite personal connections. As one expert explained: *"You are in contact with nature... As humans, you start to reflect on your own ego and not really want to control everything, and you feel a kind of relief."* Second, *temporal rhythms* such as tides, light shifts, or seasonal cycles were also viewed as essential yet rarely integrated indoors. One participant reflected: *"In nature, time is dynamic—you see tides coming in and out, shadows shifting... There's a rhythm to it that's deeply tied to our*

[5]https://standard.wellcertified.com/well
[6]https://www.studioroosegaarde.net/project/waterlicht
[7]https://www.irisvanherpen.com/collections/architectonics

(a) Iris van Herpen's Nautiloid

(b) Daan Roosengaarde's Waterlicht

Figure 4: Examples of biophilic expression through art: (a) Studio Iris van Herpen's creation inspired by aquatic life forms. Image credit: All rights reserved by Iris van Herpen BV, Iris van Herpen. Accessed 14 May 2025. (b) *The Waterlicht* project showcasing life on a flooded Earth. Image credit: Daan Roosegaarde www.studioroosegaarde.net. Accessed 14 May 2025.

perception of being in nature." Finally, *infinity* was described as another overlooked aspect: *"Views of the horizon or infinite space—like transparent designs or reflective surfaces—can create an illusion of endlessness that connects users to the vastness of nature."*.

T5 - Multi-species Flourishing in Buildings: Historically, architecture has excluded or controlled non-human species—Vitruvius' "primitive hut" [75, 119] symbolises architecture's functional origins, prioritizing human protection and comfort. Modern practices often perpetuate this trend through impermeable designs that hinder ecological integration. Even within buildings that incorporate natural elements, one expert noted: *"Most of the time we get requested a plant with hydro grains... the plant itself is in a hibernation state. It's surviving but not really actively doing anything."* In contrast, multi-species flourishing considers buildings as *opportunities* for ecological interaction and care between humans and non-humans.

This perspective informs design approaches suggested by experts. First, embedding *encounters* with non-human species can foster meaningful interactions. As one expert noted: *"Creating spaces for multi-species social encounters can encourage new experiences for us.... and also shared use and mutual respect for the non-human."* Second, *dedicated spaces* for multi-species flourishing are essential. While pollinator gardens [130] and insect hotels [60] are popular outdoors, indoor spaces must support local life, including during building off-hours. Connectivity is vital; transitional spaces like ecological corridors [137] can link fragmented habitats, enabling species and ecosystem interaction.

Technology was suggested in managing these interactions: *"...a smart cat door can open at certain times for a specific cat. You could extend this to ecological passages... sometimes there may be too many mice, so we close it or we try to balance between different ecological communities. Technology could monitor and try to manage this relationship."* Finally, "Imagination" was highlighted as a critical design tool (also discussed by Fernández et al. [39]): *"Imagination allows us to see beyond functional limitations and engage with the possibilities of truly integrated ecological systems."*.

T6 - Biophilic Design for Social Justice: Two experts raised the potential of biophilic design as a means of addressing social inequities by fostering inclusive, community-focused environments. Research supports this premise—nature and affluence are linked in urban settings, where areas with abundant greenery tend to be wealthier, while under-resourced areas often lack access to nature [134]. This disparity extends to indoor spaces as well: *"Biophilic design is frequently seen as a luxury, rarely accessible to those who might benefit most from it."* We saw that most biophilic projects mentioned by experts, whether from their own work or known examples, were heavily concentrated in corporate developments.

Despite this, biophilic design can support marginalised communities by combining ecological stewardship with social inclusivity [97]. First, it can foster a sense of ownership through participatory design, where *collaborative biophilic projects* bridge gaps between professional intent and the lived experiences of diverse users. Such projects can promote economic uplift by integrating urban agriculture or green infrastructure, providing community resources and ecological benefits. Second, biophilic design can help meet the emotional and social needs of transient or vulnerable populations by creating spaces that provide refuge and healing (also shown in existing works [29, 118]). Experts emphasised programming to keep such spaces active and inclusive. As one noted, *"Programming ensures that these spaces don't just exist as beautiful designs but are used. It's like creating a modern version of a church—a space for community and solace."*

In literature, in ancient temple courtyards, biophilia served collective and inclusive functions [49]. The industrial era, however, shifted design priorities toward efficiency and density, often at the cost of natural elements. While biophilic design is re-emerging as a response to ecological and social challenges, its implementation often reflects existing inequalities. In corporate settings, it manifests as immersive features like indoor ponds; in underserved contexts, it is reduced to token greenery. Reclaiming biophilic design's communal, inclusive legacy may help address these disparities and ensure its benefits reach those who need them most.

T7 - The Body in Biophilic Design: The human body is central to biophilic design—as both observer and participant, it senses and responds to environmental cues: *"...the human body—as a natural sensor... it's the first means we can use to recreate our inner connection with nature."* This view builds on Shusterman [112], where bodily scale and orientation guide spatial design. *Somaesthetic design* in HCI extends this perspective, highlighting bodily awareness and the reciprocal relationship between body and environment[57, 58].

Body sensitivity emerged as a critical design principle, advocating for delicate, nuanced interactions with natural elements, like moss textures or rustling leaves, to foster deep somatic connections. Sensitivity was framed through a feminist lens, addressing gendered differences in somatic needs. Experts discussed how hormonal cycles and bodily rhythms influence indoor experiences (also researched in gender studies [52, 72]), and how buildings should respond to these differences. Technology was offered as a means to respond to feminist bodily needs: *"And in an ideal building, it is more related to how our body works and how we feel and how we can be the most happy and productive in that sense. And then technology could analyse your body—body temperature, for example. So for a woman's body, where are you in your cycle? What do you need?"*. Another highlighted the importance of augmenting this sensitivity to make biophilic experiences accessible: *"You need to be sensitive to first catch the different benefits a biophilic experience can offer. And we have seen that the female body is more sensitive..."*. We discuss this in greater detail in section 6.

Bodily awareness, biophilia, and architecture were also discussed through what one expert termed the "living effect" (briefly explored in HCI [116]), highlighting elements that evoke growth and vitality in artificial spaces. This idea extends to the concept of *bodily flow*, where design elements such as meandering paths or kinetic installations not only encourage physical movement but also create an awareness of the interaction between the body and its surroundings [25, 112]. By actively guiding movement, such designs enable occupants to experience spaces in a way that feels organic and intuitive, enhancing their connection to both the environment and their own embodied presence. The somatic-biophilic lens thus offers an alternative lens on how biophilic design can support deeper connection to nature and self.

T8 - Biophilic Design for Occupant (Dis)Comfort: Experts highlighted that biophilic design should challenge traditional comfort norms: *"Comfort should not always about ease; sometimes it's about engagement. And I think that nature's unpredictability makes us feel alive, even when it's inconvenient."* In smart buildings, for example, sunlight enriches sensory experiences with light and shadow (called Komorebi [138]), but is often "corrected" through automated shading systems [24]. Similarly, natural elements perceived as "messy" or unpredictable are frequently avoided: *"People think it's (referring to a landscape project) very messy, and they are reluctant to interact with the space. But sanitised versions limit and reduce our connection to the natural world."*

In nature, discomfort is often experienced as *duality*. Walking barefoot on sand can be grounding, yet painful (e.g. from sharp shells). One expert reflected: *"...I am really enjoying being in nature but it could also a lot of time be a bit scary, bring fear...like innate fear when you are confronting with nature."* Yet, these moments of discomfort can catalyse personal reflection: *"Friction fosters reflection. When we're uncomfortable, we're more likely to pay attention and find meaning in our surroundings. A lot of new reflection actually comes from this friction in contact with nature."* This tension between comfort and discomfort seems inevitable. Designing for biophilic (dis)comfort could involve strategic oscillations between ease and challenge, mimicking natural rhythms: *"The stepping stones (installed in the midst of a footpath) reduce paving...you really have to watch your step, but you feel like you're passing through a natural overgrown area."* Discomfort could also be framed as a trade-off, where users accept minor inconveniences—such as insects from pollinator plants indoors—for greater ecological benefits. This is discussed in section 6.

In productivity-focused spaces, biophilic (dis)comfort raises critical questions of balance and appropriateness. While greenery and lighting enhance focus (e.g. [4]), one expert noted: *"There's an appetite for more greenery, especially after the pandemic, to try to make sure that the spaces indoors actually do have the qualities that are a bit more, let's say, friendly and encourage people to come back and work."* How can (dis)comfort align with expectations in workplaces or learning environments? Finally, limiting design to ableist bodies is problematic. Overly wild, unpredictable elements may be inaccessible to individuals with mobility or sensory sensitivities: *"you need to see if everything is accessible. You could have parts like that (referring to a project that designed for exploratory pathways paved with stones) but it needs to be wheelchair accessible. Otherwise, it can limit (someone's) movements."*.

6 Design Opportunities for Multisensory & Multidimensional Biophilic Interactions

We next synthesised Topics (TO1–TO7) and Themes (T1-T8) into five actionable design directions (DO1–DO5). We also explore how emerging technologies can reimagine biophilic experiences in smart environments, summarised in Table 2. Although technology was not the primary focus of our interviews, experts highlighted its potential, particularly in themes related to art (T2), multi-species coexistence (T5), and embodied experiences (T7) (c.f. section 4). We used these discussions to support our design opportunities with technology enablers.

DO1: Designing for Emergent Natural Processes. To foster deeper connection with nature, smart buildings must support evolving, self-regulating, and unpredictable qualities inherent in natural processes (see section 5). Unlike mechanical systems with repetitive patterns, natural processes evolve unpredictably, creating emergent properties—where small changes lead to transformative shifts [31]. For example, ecosystems may adapt to support new species or behaviours, reflecting nature's novelty and resilience [23, 100]. Designing with this quality means embracing flux and variability—qualities rarely integrated into current smart building design (e.g. Economidou [37]'s vision of moving walls and talking floors). For IxD, this prompts the development of tools and methods that foreground emergence and unpredictability. For smart building researchers, it suggests investigating how such features influence occupants' comfort and emotional responses.

Realising emergent processes in smart buildings calls for technologies that enable unpredictability and self-regulation [31]. This

Table 1: An overview of the eight themes created from a reflexive analysis of the expert interviews. For each theme, we provide the theme name, a brief description, the top three codes associated with the theme, and the number of supporting quotes.

Theme	Description	Example Codes (n=3)	Count
T1 - Ecological Authenticity and the Essence of Nature in Building Design	This theme revisits the philosophy of biophilic design as a deep, authentic connection with nature that aligns with its processes, patterns, and non-human agency. However, this philosophy is often diluted or lost in translation during the design process, leading to tokenistic or anthropocentric implementations. The focus is on preserving the integrity of ecosystems by designing in harmony with their natural cycles rather than imposing human-centred control.	Shallow adoption and Tokenism; Re-framing Nature as Active Participant; Simplified perceptions of nature	75
T2 - Art as an Expression for Biophilic Experiences	This theme examines our inclination to represent and connect with nature through artistic expression. It discusses how art and technology can combine to enable biophilic experiences to create participatory, restorative, and culturally resonant designs.	Technology as participatory "material"; Soft fascination; Natural behaviours through biophilic art	29
T3 - Biophilic Design for Ecological Empathy	Biophilic design emerges as a medium for fostering environmental awareness, ecological empathy, and sustainable behaviours. By integrating biophilic principles into design, spaces can support active learning, encouraging a sense of stewardship and collective responsibility for the natural world. This theme emphasises how educational biophilia—using interactive, sensory, and participatory approaches—can cultivate biophilic behaviours in occupants.	Nature awareness as a catalyst for nature respect; Participatory stewardship of nature; Technology for amplifying living elements	52
T4 - Multi-sensory and Multi-dimensional Biophilic Design	This theme emphasises the need for expanding biophilic design in indoor spaces beyond visual and greenery-centric approaches to include sound, smell, touch, and movement as well as including more complex and layered environmental interactions.	multi-sensory experience, Experience of sublime, Movement and fluidity in design.	88
T5 - Multi-species Flourishing in Buildings	This theme envisions biophilic design for supporting environments where diverse species can coexist, thrive, and contribute to ecological resilience. It emphasises the agency of non-human species as active building "occupants". The focus is on creating opportunities for non-human species to express their natural behaviours, flourish in human-altered spaces, and contribute to shared ecosystems.	Living ecosystem design approach, Integrating with inter-species practices, Non-interventionist design approach	65
T6 - Biophilic Design for Social Justice	This theme examines biophilic design for social inequities by fostering inclusive, participatory, and community-focused environments. It critiques the exclusivity of biophilic design as a "corporate culture" and advocates for equitable access to natural, restorative spaces. The focus is on empowering marginalised and vulnerable communities through designs that provide safe spaces for emotional escape and support active social programming.	Biophilic design as an introverted design privilege, Spaces of injustice, Biophilia for community building	63
T7 - The Body in Biophilic Design	This theme explores the role of the human body as a site of interaction and perception within biophilic design. Drawing on somaesthetic principles in built environments, which emphasise bodily awareness, sensory engagement, and movement [112], this theme explores how somaesthetic design can provide an alternative lens to can foster meaningful biophilic experiences, fostering awareness of nature, and of self.	Human body as a sensor for biophilic experiences, sensitivity as a BD principle, Movement and fluidity for bodily design	30
T8 - Biophilic Design for Occupant (Dis)Comfort	This theme challenges traditional notions of comfort by creating environments that evoke both comfort and discomfort. It examines how embracing elements of discomfort including unpredictability and even fear can be a meaningful aspect of the nature experience within indoor spaces. By embracing these "unexpected" aspects of nature, this theme examines the opportunities and challenges around designing for biophilic (dis)comfort as a means for connecting with nature.	Friction in contact with nature; Rejection of Uncontrolled Nature; wildness versus usability	42

could involve repurposing the idea of "third landscapes"—unmanaged, dedicated indoor areas where technology supports natural processes [31]. *Stochastic algorithms* in IoT systems might trigger environmental changes within probabilistic bounds, such as fluctuating light or airflow that reflects external wind variability [65]. *Generative AI* could create evolving soundscapes in response to real-time environmental data—like wind speed, temperature, or occupancy, mirroring natural acoustic dynamism [13, 98]. *Collaborative AI ecosystems* [74] might coordinate lighting, shading, or HVAC systems to behave in interdependent, temporally unfolding behaviours, generating a living quality within the building—similar to explorations in computational architecture [129].

DO2: Designing for Occupant Body Sensitivity. This opportunity positions the human body as an interface and an active participant in biophilic experiences. By encouraging occupants to notice, understand, and reflect on their embodied sensations, buildings can foster deeper connections to the surrounding biophilic conditions (c.f. Theme 7, section 5). For IxD, this opportunity challenges the prevailing paradigm of uniform sensory experiences in smart buildings, supporting first-person, body-centred interactions with biophilic conditions.

Building on embodied urban HCI [44], technologies could amplify bodily awareness of ambient, subtle biophilic cues [121]. Haptic or thermal *wearables* can translate airflow or temperature into tactile feedback. For instance, a wearable might vibrate or warm slightly to guide users to align themselves with airflow patterns in a room, encouraging a restorative state [106]. *Smart building façades could act as interactive sensory mediators* [102, 115], responding to environmental changes such as "sweating" on hot days or during higher humidity levels before rain, connecting them with natural phenomena. *Augmented Reality (AR)* can visualise real-time physiological data, such as heart rate or breathing, overlaying this information onto the user's environment (similar to using AR for visualising indoor air pollution [61]). An interface could, for instance, illustrate how proximity to plants or exposure to natural light impacts physiological responses, enabling reflection through a biophilic lens. Finally, *digital journaling tools* like "biophilic body maps" could incorporate feminist and inclusive perspectives by allowing users to document and share how their identities and contexts shape their interactions with biophilic elements [123]. Aggregated body maps data from multiple users could reveal how groups engage with biophilic spaces, offering input for designing communal environments for maximising biophilic interactions.

DO3: Designing for Biophilic (Dis)Comfort. Smart buildings should incorporate moments of *(dis)comfort* to deepen human connections to nature (c.f. Theme 8, section 5). By integrating *frictional* design elements inspired by biophilic surroundings [11], IxD can create experiences that deliberately use discomfort to provoke reflection and inspire new understandings of the natural world [99, 102].

IoT-enabled technology in flooring systems could simulate *tactile interactions* by subtly cracking or shifting underfoot (e.g. Economidou [37]'s moving floors), symbolising ecosystem fragility and prompting occupants to reflect on climate impact. These might be augmented with ambient soundscapes, like the cracking of brittle surfaces to highlight ecosystem fragility [7]. We previously discussed *biophilic (dis)comfort as a trade-off*, where occupants accept minor inconveniences for greater ecological or experiential benefits. Buildings could provide context for discomfort-inducing features, helping occupants interpret their experiences. For instance, AR overlays visualise indoor pollinator corridors with representations of bees or butterflies, paired with subtle sensory cues like vibrations or ambient buzzing sounds, encouraging reflection on shared habitats [84]. Discomfort could extend to *experiences of risk and discernment.* As one expert noted, *"Taste is a sense of caution... even in nature, we exercise a certain judgment."* Interactive installations could explore this cautious quality through scent or visual provocations that elicit hesitation and curiosity, prompting reflection on sensory boundaries (e.g. risk expressing design [36]). In workspaces, designers could introduce *"productive biophilic discomfort"* [3]. For instance, smart lighting systems in light-scarce regions might dim briefly, mimicking cloud cover. While this momentary discomfort could disrupt focus, prompting occupants to seek natural light.

DO4: Designing for Biophilic Equity. Through biophilic equity, smart buildings can address the systemic disparities in access to nature experiences and their benefits in indoor spaces, which has often been uneven (c.f. Themes 2 and 6, section 5). This necessitates prioritising public buildings and shared urban environments for biophilic design. For IxD and smart building researchers, biophilic equity offers opportunities to tackle the inequities through participatory technologies, therapeutic tools, and cultural storytelling.

One potential application is *digital platforms for participatory design* [6]. Interactive apps or web platforms could enable community members to actively contribute to shaping biophilic spaces [6, 47]. For instance, users could suggest plant species, vote on design features, or provide input that reflects their cultural and ecological values. *Biophilic connection technologies* could also serve as therapeutic tools for marginalised groups such as displaced refugees or at-risk youth. Immersive virtual reality (VR) experiences could transport users to calming, nature-rich environments such as forests or ocean providing solace amidst hardships. *Digital storytelling* through architectural features [21] in community centres or youth facilities could host interactive art installations or digital projections that celebrate the cultural and ecological histories of under-represented groups (like the co-design with displaced youth [41] to develop wayfaring solutions). For example, public spaces could visualise the biodiversity of regions associated with displaced communities, fostering a shared ecological narrative and recognising their contributions to environmental stewardship.

DO5 - Designing for Relational Encounters with Nature. Smart buildings foster relational encounters by encouraging empathy, care, and mutual growth between humans and nature (c.f. Themes T3, T1, T5, section 5). It makes nature's needs visible to promote awareness and responsibility [42, 78]. Historical examples of Persian gardens embodied this by requiring active care from humans who maintained irrigation systems, creating ecosystems that rewarded engagement with fruit-bearing trees [70, 71]. For researchers, designing for relational encounters with nature opens pathways for technologies fostering individual and collective empathy. It also calls for studying how group dynamics shape engagement within biophilic spaces.

Relational encounters with nature can be fostered by "surfacing" the presence and processes of ecological systems [42, 78, 116]. This includes "cues for care" inviting reflection (discussed in T3 section 5). Drawing from technology design in Relational-Cultural Theory (RCT) [32, 73, 132], IoT sensors, for example, can track soil or light and translate data into interactive cues. For example, *projection walls and ambient displays* could show environmental changes in shared spaces like lobbies or meeting rooms, supporting shared group responses to support biophilic elements [82]. *Empathy-building technologies* could further enhance relational encounters by shifting perspectives from human to non-human [42]. AR, for example, might simulate a "plant's-eye view" of human actions [120], showing how behaviours like touching or crowding impact growth and

Table 2: A summary of design opportunities for supporting novel biophilic experiences in smart buildings. Each opportunity is summarised with a short description of how the smart building can be designed, corresponding themes, and three example technology possibilities. Theme 4 on multisensory and multidimensional experiences is not explicitly mentioned here as it is an underlying notion across all design opportunities. This is discussed further in section 7.

Design Opportunity	Description	Associated Theme(s)	Technology Examples (n=3)
DO1 - Designing for Emergent Natural Processes	Support evolving, self-regulating, and unpredictable qualities of natural processes to create opportunities for "new" behaviours to emerge.	T1, T2, T5	Stochastic IoT algorithms for environmental variability; generative AI for evolving soundscapes; collaborative AI ecosystems for generating complex building responses.
DO2 - Designing for Occupant Body Sensitivity	Position the human body as an active participant in biophilic experiences by amplifying embodied awareness to surrounding biophilic conditions.	T7	Haptic and thermal wearables for tactile feedback; AR to visualise physiological responses to natural elements; digital journaling tools for documenting interactions.
DO3 - Designing for Biophilic (Dis)Comfort	Employ controlled discomfort in biophilic contexts to help occupants reflect on such moments and deepen human connections with nature.	T8	AR overlays for pollinator corridors; soundscapes simulating ecosystem fragility; interactive installations exploring sensory boundaries around risk.
DO4 - Designing for Biophilic Equity	Actively counter systemic disparities in access to nature-rich experiences by prioritising inclusive and participatory biophilic design that benefits underserved communities.	T2, T6	Digital platforms for participatory design; VR experiences for immersive nature-rich environments; digital storytelling through projections or art installations.
DO5 - Designing for Relational Encounters with Nature	Foster care, empathy, and shared responsibility by making nature's often invisible processes visible and encouraging collective interaction.	T1, T3, T5	IoT sensors for ecological monitoring; AR for perspective-shifting experiences (e.g. plant's-eye view); AI-assisted wearables for ambient ecological awareness.

health. *Ecological interactions awareness* using AI-assisted wearables (e.g. similar to outdoor bird awareness bracelets [78]) could be adapted for indoor environments, highlighting moving pollinators or subtle natural odours within biophilic spaces.

7 Discussion of Findings: Implications For Smart Building Research

Our findings include seven *topics (T1-T7)*, eight *themes (T1-T8)*, and five *design opportunities (DO1-DO5)*. While *topics* served as an organising scaffold, here we focus on how the *themes* and *opportunities* extend HBI research: *thematically*, by expanding the experiential and ecological vocabulary of interaction, and *generatively*, by proposing new design directions and technological opportunities. We then share messages for a multisensory–multidimensional (MS–MD) approach to biophilic interaction. Finally, we discuss tensions in applying biophilic design and study limitations.

7.1 Thematic Contributions: Expanding the Vocabulary of HBI

Our findings contribute to HBI by expanding its design vocabulary—re-framing smart buildings as *ecological interfaces* that surface natural rhythms and multispecies presence **(T1, T3, T5)**. While prior HBI work has largely prioritised comfort and behavioural control [2, 95], ecological awareness and more-than-human perspectives remain under-explored. Through our themes, we surface terms such as *multispecies flourishing*, *biophilic (dis)comfort*, and *ecological interface* to capture this shift. Second, we foreground *multisensory, somatic engagement* in interaction design. Experts envisioned systems that respond to the body through movement, rhythm, and material sensitivity—beyond visual dashboards or app-based feedback **(T2, T4, T7, T8)**. While soma design has highlighted embodied experience in HCI [58], our findings extend these insights into architectural space, suggesting how buildings themselves may become expressive, responsive participants in biophilic interaction. Finally, our themes emphasise the *social and cultural responsibility* of smart environments. Although HBI has begun to address equity and privacy [90], it often overlooks how cultural values, neurodiversity, and uneven access to nature shape lived experience. Biophilic design offers a way to support diverse bodies, histories, and sensory needs—enabling justice-oriented smart environments [28].

7.2 Generative Opportunities: Biophilic Interaction Through Technology

Our design opportunities contribute to HBI by reimagining how technology can support biophilic interaction. These contributions open new conceptual and material directions for IxD in the built environment. First, we reposition *sensing* from a behavioural optimisation [26] mechanism to a medium for ecological expression. Speculative deployments of stochastic IoT and generative AI render light, sound, and air movement as expressive materials—carrying the rhythms of weather, growth, or animal migration **(DO1, DO5)**. This extends sensing beyond data extraction into ambient ecological storytelling. Second, shifting from traditional HCI perspectives, we build on soma design to propose *embodied interactions at architectural scale*. Haptic panels, responsive facades, and AR overlays attuned to movement and physiology foster bodily and interpretive engagement with biophilic environments **(DO2)**. These approaches challenge the dominance of reactive, screen-based interfaces in

smart building design [102, 122]. Third, we envision *participatory and justice-oriented* directions for HBI. Our opportunities include VR platforms for community co-design and systems that register non-human presence—such as pollinators or wildlife corridors **(DO3, DO4, DO5)**. These interactions extend critical HCI into architectural contexts [56], positioning smart buildings as spaces of care, activism, and more-than-human coexistence.

7.3 Reflective Messages for Multi-sensory and Multi-dimensional Biophilic Interaction in HBI

Smart buildings must evolve to support richer, more ecologically attuned forms of interaction, aligned with a multisensory - multidimensional (MS–MD) approach. To support this reorientation, we distil five reflective messages by reflecting on the combined study findings, intended to guide future HBI design and research. First, biophilic interaction should be scaled across different *perceptual levels*—from micro (e.g. tactile encounters through fingertips), to meso (e.g. room-scale soundscapes or kinetic partitions), to macro (e.g. building-wide lighting systems reflecting outdoor conditions). Second, building on this multi-scale sensitivity, interactions should unfold *temporally*, allowing environments to act as narrative spaces shaped by seasonal rhythms and lived memory. Third, biophilic systems should strive for *coherence* across sensory modalities, so that light, sound, temperature, and motion collectively evoke ecological meaning rather than functioning as disconnected features. Fourth, well-timed "disruptions" or moments of *surprise* can play a powerful role—fostering curiosity, reflection, and deeper connection to place and self. Finally, biophilic interaction must remain *inclusive*, designed with sensitivity to diverse bodies, access needs, and cultural ways of sensing and being. Together, these messages reframe biophilic interaction as interpretive (inviting meaning-making) rather than prescriptive (dictating responses), and reciprocal rather than extractive—qualities that are critical as HBI moves toward more-than-human, justice-oriented futures.

7.4 Discussion of Biophilic Interaction Design Tensions

The opportunities outlined in this paper highlight a critical tension between technological advancement and the intrinsic, cultural, and emotional values of nature [48]. This "technocratic fallacy" reflects the risk of framing biophilic design through an overly technical lens. Such framings may prioritise quantifiable metrics, such as run-time efficiency of IoT systems managing building conditions, side-lining the intrinsic qualities of nature that evoke awe, connection, and belonging. Detached, technical discourse can further disconnect occupants from the authentic and restorative qualities of nature. We need to remain mindful of such framings and ensure technological solutions complement the humanistic and ecological principles of biophilia [66, 68, 133].

Biophilic design also entails a reciprocal relationship. One side concerns humans benefiting from nature—through sensory stimulation and well-being; the other involves nature benefiting from us—through care, stewardship, and infrastructural support. Expert visions largely focused on the former, envisioning how smart buildings might enhance human experience. This human-centred focus mirrors a broader gap in HBI, where technologies often overlook ecological reciprocity. Yet in the face of climate change, biodiversity loss, and environmental degradation, reciprocity is essential. Smart buildings are not passive—they reshape ecosystems, consume resources, and produce waste. They must therefore be designed not only to evoke nature, but to sustain it. Moving forward, we call for biophilic design in HBI to be critically reoriented toward ecological responsibility and care for more-than-human life.

7.5 Discussion of Limitations and Future Work

This work reflects our positional lens as researchers working across HCI, architecture, and interaction design, and is not without limitations. First, most experts were European, and their imaginaries may not reflect broader societal, Indigenous perspectives on biophilic interaction. While we observed disciplinary differences—such as technical versus aesthetic framings—most experts shared a design-forward orientation, potentially skewing the findings toward certain types of interventions. Some offered perspectives in social justice or spirituality, but these remained peripheral. As one noted: *"European architecture focuses on buildings for human design—a lot of this comes from the dominance of Christianity, which emphasised actions in favour of humankind. This contrasts with the perspectives of say the Indigenous tribes in Australia..."*. Future work should intentionally engage more diverse world-views and situated knowledge.

Second, we chose to conduct interviews over scoping or systematic literature reviews. We find that interviews allowed us to capture tacit knowledge, practice-based reflections, and design imaginaries that may not yet be documented in academic discourse. Moreover, the initial coding was conducted by a single author. Although findings were iteratively discussed and refined, this may introduce subjective emphasis. Future work could extend our interview data with methods—such as co-design, literature reviews, or in-situ prototyping—to broaden empirical grounding. Finally, the technological examples linked to our design opportunities were interpretively developed. Although not discussed directly in interviews, we drew on our disciplinary expertise to propose plausible interventions—such as generative AI and ecological sensors—chosen for their conceptual resonance with the experiential qualities described by experts. We offer these as illustrative pathways to expand the HBI design space, and we invite future research to adapt, extend, or critically examine these interventions through prototyping and participatory methods.

8 Conclusion

This study set out to gather expert ideas, considerations, and imaginaries around the potential for biophilic experiences in buildings. Our goal was to identify opportunities for inspiring the future design of smart buildings that move past addressing occupants' physical comfort and consider the role of these buildings within larger ecological systems. Our work contributes to the growing discourse on integrating biophilic principles into smart building design. By bridging the legacy of biophilic architecture with emerging technologies, we aim to inspire research and practice that goes beyond functionality to include the ecological, cultural, and sensory dimensions of human experience through biophilic smart buildings for human and ecological flourishing.

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A Semi-Structured Interview

A.1 Outline of Questions

Here we provide an outline of the interview questions used. Within each interview topic (e.g. Introduction), we show examples of some of the different questions that were asked based on the nature of the conversation. Given the semi-structured nature, we did not adhere to the sequence of these questions within each topic.

A.1.1 Introduction. Briefly introduce the study's focus on multisensory biophilic design within smart buildings highlighting the interest in MSB around.

(1) Could you share your background in (relevant text)—particularly regarding your experience with biophilic design?
(2) Interpretation of Connection: When people talk about this goal for design that allows "a deeper connection to nature" in built environments, what do you think that means?
(3) How does this resonate with your experiences or design philosophy?
(4) (give context on smart environments) What are your thoughts on integrating biophilic elements within smart environments?

A.1.2 Grounded Insights. Explore the practical and technical aspects, identifying research-based perspectives, technical insights, criticisms, and relevant examples in MSB design.

(1) Existing Design Limitations: (...our desk research shows...) Current biophilic designs are often visually focused (e.g. use of lights, living walls, nature-inspired privacy screens, green colours). Do you agree, and why do you think that is the case?
(2) Sensory Engagement: Which sensory elements (e.g. smell, texture, sounds, even vibrations) do you think could be most effective in creating a sense of immersion or connection to nature within built environments?

A.1.3 Challenges and Feasibility.

(1) What [technical] challenges do you anticipate when designing multi-sensory biophilic spaces, such as those incorporating sound, touch, or scent? (depending on the background - focus on either future material possibilities, future concepts, or technology)
(2) Speculating on Future Biophilic Technologies: Are there any emerging technologies or materials that you think could enhance multi-sensory biophilic design? How might these help create environments that are more 'alive' and responsive?
(3) Criticisms: Are there any problems you have with the way we consider nature design in its current applications?

A.1.4 Experiential Perspectives. Gather insights on personal experiences, professional values, and context-specific knowledge regarding MSB design.

(1) Body-Nature Connection: Can you share an experience or a project where a built environment made you feel deeply connected to nature? Which aspects were most impactful?
(2) Multi-sensory: Similarly, are there any specific projects you've worked on or encountered that successfully engaged multiple senses? Do you remember what impact it had on you?
(3) Values and Priorities: What core values (e.g. peace, healing, diversity) do you think should shape the design of a MSB space?

A.1.5 Visionary Outlooks. Encourage exploration of future visions and speculate on potential evolutions in MSB design.

(1) Exploring Enhancement Possibilities: "If you could enhance one sensory aspect of biophilic design in current spaces, what would it be, and how do you imagine it might affect occupants' experiences?"
(2) Speculative Scenarios: "Picture a future environment that seamlessly blends technology with natural elements—for instance, a space that feels like it 'breathes' (inhales and exhales). Are there any such forward-thinking or aspirational concepts you've come across—or envisioned yourself—that could inform the future of multi-sensory environments?
(3) Future Visions: If you could design a biophilic environment that integrates various sensory responses to create a deep connection with nature, what would this look and feel like?

A.1.6 Conclusion and Reflection. Wrap up with open reflection and any additional thoughts.

(1) Do you see biophilic design gaining more importance in the future where spaces are increasingly smart?
(2) What role do you see for architects/designers in shaping these sensory-rich, adaptive spaces?
(3) Finally, could you share a source of inspiration for multisensory biophilic design—a book, movie, place, piece of art, or any other experience that has influenced your thinking in this area? Any additional thoughts or anything else that you would like to mention?

B Overview of Experts

Table 3: Participant Demographics

Role	Domain	Geographical Context	Stated Biophilic Expertise
Architect (Urban Designer)	Industry	Europe	Land and ecological planning
Researcher (Urbanism), Writer, Architect	Academia, Industry	Europe	Environmentalism and speculative design
Architect - Founder	Industry	Europe	Smart building technology development
Co-founder - Green Designer	Industry	Europe	Nature awareness and sensory biophilic practices
Research Fellow	Academia	Europe	Quantitative research
Senior Associate	Industry	Europe	Sustainable and green certifications
Research Fellow	Academia	Europe	Urban renewal and reuse of green spaces
Researcher (Occupational Health)	Academia	Europe	Smart offices for sensory well-being
Senior Architect	Industry	North & South America	Culturally relevant design
Senior Architect	Industry	Europe & Central Asia	Multi-sensory strategies in architecture
Architect - Founder	Industry	Europe	Environmental design philosophy
Architect (Senior Design Lead)	Industry	Europe & Middle East	Contextual and climate-sensitive design
Researcher (Design Informatics)	Academia	Europe	Interactive interfaces for smart buildings