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# Comparing mixed reality use in ecologically distinct urban sites: embodied tools for participatory environmental design

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Mixed reality (MR) environments offer new opportunities for embodied interaction in participatory design processes. This study evaluates whether mobile MR tools influence ecological awareness and co-design behavior across two distinct urban settings. Twenty participants from architecture and design disciplines took part in structured workshops involving MR-supported design tasks. Sessions were conducted in a spatially bounded university courtyard and on a semi-natural coastal island. Both sites were selected for their differing environmental characteristics, allowing a comparative assessment of MR's effectiveness under varied ecological conditions. Participants used mobile augmented reality interfaces to visualize and situate ecological design proposals, including tree-based structures, habitat-supportive elements, and spatial overlays oriented toward nonhuman actors. Observational logs, post-session surveys, and coded design artifacts were used to evaluate behavior. Ninety percent of island participants and seventy percent of courtyard participants integrated ecological elements into their final designs. Reflections revealed more frequent references to nonhuman spatial actors among island participants. Reported cognitive fatigue and difficulty using the MR interface were higher in the island group, with 60 percent citing spatial or interface overload. Half of the participants also expressed uncertainty about authorship and the persistence of their digital contributions. These findings suggest that MR interfaces can support multispecies engagement and participatory ecological design, but their effectiveness depends on the sensory density, narrative framing, and infrastructural legibility of the spatial context. The results provide preliminary evidence that MR can function as a perceptual and participatory tool for inclusive environmental design under specific spatial and cognitive conditions.

KEYWORDS

**mixed reality, participatory design, ecological awareness, embodied interaction, urban environments**

## 1 Introduction

Urban design increasingly demands forms of engagement that move beyond consultation and visualization. Ecological breakdown, climate volatility, and the increasing presence of nonhuman actors in urban systems are reshaping how environments are encountered and interpreted (Albrecht, 2017). While participatory design frameworks have evolved to accommodate more diverse human perspectives, they continue to struggle with forms of attention that exceed the human scale (Latour, 1993). Much of the infrastructure of participation—maps, diagrams, renderings, and interfaces—assumes that the world becomes knowable through abstraction. But ecologies do not always conform to visual representation, and spatial decisions often rely on modes of perception that are situated, embodied, and multispecies (Manzini, 2015; Beatley and Newman, 2013; Whatmore, 2002; Hall, 1966).

The study uses mobile Augmented Reality (AR) tools to support spatial deployment, but we adopt the broader term Mixed reality (MR) to reflect the perceptual, ecological, and infrastructural dimensions central to our analysis. MR is used throughout to frame these interactions conceptually rather than technically. MR technologies offer designers the ability to situate digital content directly within physical environments. In architecture and spatial practice, these systems have been used to support iterative form-making, prototyping, and annotated environmental overlays (Milovanovic et al., 2017; Davis and Wagner, 2024). Mobile AR platforms in particular allow for full-scale, location-aware deployment of speculative elements that engage the body in real time (Klopfer and Squire, 2008). However, these tools are often evaluated in terms of usability, responsiveness, or visualization quality, rather than their capacity to mediate attention to nonhuman systems. The question of how MR might operate as an epistemic device, one that helps designers perceive ecological phenomena differently, has been raised in theory but remains underexplored in practice (Offenhuber, 2017; Parisi, 2013).

MR is often framed as an interface, but it may be more accurately understood as a perceptual infrastructure. The ability of these systems to direct, withhold, or reframe user attention means they do more than display content; they shape what becomes perceptible in a given environment (Zylinska, 2020). In participatory contexts, this shift has significant implications. It determines not only which actors are included in a process, but which presences are rendered noticeable in the first place. Infrastructural decisions—such as how models are positioned, what gets annotated, or where feedback occurs—encode epistemic hierarchies. They define the terms through which space becomes legible.

This insight is especially critical in ecological design, where the conditions being addressed often exceed discrete objects. Root systems, drainage thresholds, habitat overlaps, and seasonal behavior patterns do not readily appear within the representational vocabulary of most MR applications. Hinchliffe and Whatmore (2006) emphasize that nonhuman actors in cities are not residual but integral to spatial formations (Wolch, 2007). To engage these actors requires tools that do not only simulate but reorient perception. Haraway (2016) and Tsing (2015) argue for forms of design that remain open to ecological indeterminacy, emphasizing contact, co-presence, and material friction over stability or closure. This entails working within environments that are not fully knowable and with agencies that are not easily represented.

In this study, we examine how MR interaction shapes ecological awareness and design behavior across two spatially bounded but ecologically distinct sites. The first, a university courtyard, is characterized by formal landscaping, infrastructural containment, and predictable circulation patterns. The second, a coastal island microzone, offers irregular terrain, open ecotones, and diffuse environmental markers. These two contexts are used to examine how MR tools function when environmental legibility and spatial anchoring vary. The workshops were structured around a three-part workflow: speculative modeling in Maya, mobile AR deployment with Adobe Aero, and immersive simulation through Unreal Engine. Participants were architecture and interior design students with design experience but no formal training in MR systems.

Rather than isolating technical performance, the study focuses on MR interaction as a situated act (Suchman, 2007). Design is not treated as the application of fixed parameters to a neutral space but as a process that unfolds through bodily orientation, environmental interpretation, and sensory friction (Ingold, 2011). This understanding draws on Alexander's (1964) description of the misfit condition in design, where form must continually adapt to contextual demands, and connects it with more recent accounts of spatial reasoning as relational and post-representational (Barad, 2003; Vardouli, 2024).

The perceptual dynamics of MR are not neutral. Studies in critical HCI have shown how the configuration of feedback loops, annotation visibility, and environmental overlays can reinforce existing spatial biases or flatten sensory complexity (Carter and Egliston, 2024; Egliston and Carter, 2022). In highly structured environments, MR may align easily with infrastructure, guiding design toward predefined anchor points. In more diffuse ecologies, however, interaction becomes contingent, demanding that users interpret unstable surfaces and ambiguous thresholds. This distinction informs our methodological framing. By comparing MR-supported design processes across two types of environmental legibility, we seek to identify not only differences in form-making, but differences in how space is sensed and understood.

This study contributes to ongoing inquiries into enabling environments by examining how MR can act as both a constraint and a catalyst. Its purpose is not to promote MR as a universal solution but to situate its function within the perceptual, ethical, and infrastructural conditions of design. By treating attention as a design method, and friction as a generative constraint, the research explores how digital tools might support more situated, responsive, and ecologically attuned forms of participatory urban practice.

# 2 Methods

## 2.1 Participants

Twenty undergraduate students from the Faculty of Architecture at (University Name, anonymized for review) participated in two structured design workshops that formed part of their ongoing studio coursework. The workshops were open to students across the architecture and interior design programs and focused on spatial experimentation and ecological reasoning using mixed reality tools. All participants had prior experience with digital modeling environments such as Maya, Rhino, and Grasshopper. None had received formal training in augmented or virtual reality systems prior to the session. The MR platforms used in the workshops were introduced through a brief onboarding phase. A summary of participant background is included in Supplementary Appendix A.

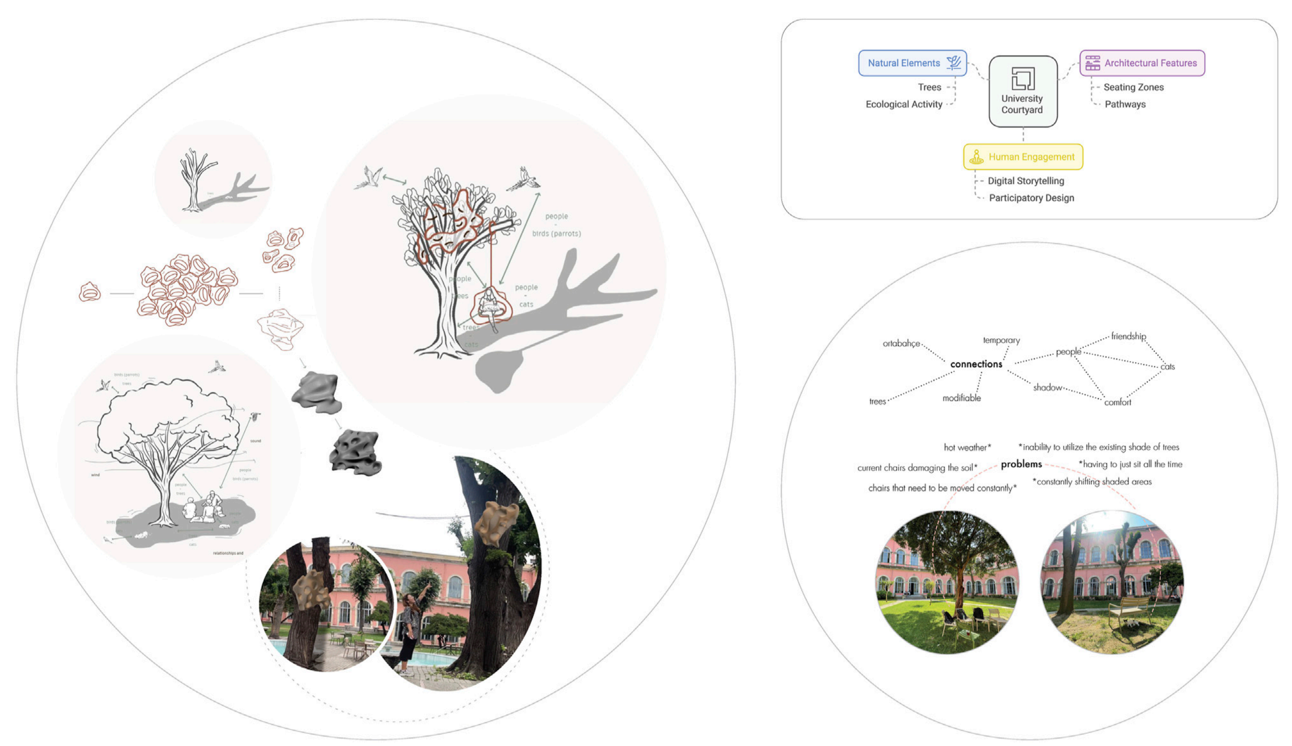


FIGURE 1
Annotated Augmented Reality overlays deployed *in situ* using Adobe Aero for ecological design interventions placed around trees, along paths, and across open zones in courtyard contexts.

## 2.2 Study sites

Workshops were conducted at two spatially bounded yet ecologically divergent urban contexts. The first site, located on a university campus, was a tree-lined courtyard enclosed by academic buildings, defined by paved circulation paths, vertical vegetation, and minimal sensory disruption. The second site was a low-infrastructure coastal island microzone, featuring ground-level flora, avian presence, saline exposure, and ambiguous boundaries between built and ecological zones. These two sites were selected to contrast controlled, institutionally embedded environments with semi-natural, open-edge ecologies. Each setting served as a testing ground for how embodied design interaction with MR tools responds to different levels of ecological complexity, spatial legibility, and infrastructural framing.

## 2.3 Experimental design

Each site hosted a single-session workshop involving ten participants. While the sequence and format were held consistent across both settings, the technological configurations varied to reflect site-responsive pedagogical intent. All participants began by developing speculative design interventions using Autodesk Maya. These models were informed by biomimetic analysis of local nonhuman species and environmental systems, encouraging students to translate observed ecological structures—such as root systems, nesting geometries, or tidal erosion patterns—into spatial proposals.

Following the modeling phase, participants used Adobe Aero to deploy their interventions in real-time via mobile AR. This allowed them to visualize their ecological proposals at full scale, anchored within the physical environment. Participants annotated these overlays with speculative functions (e.g., pollinator shelter, perching zones, vegetative scaffold) and material assumptions. This AR deployment was used at both sites.

In the island workshop only, a preliminary immersive experience was introduced using Unreal Engine. Participants entered a virtual rendering of the island's ecological layers—vegetation density, habitat zones, coastal edges—modeled from drone-captured photogrammetry and simplified ecological mappings. This VR immersion was intended not as a visualization tool, but as a perceptual primer, allowing participants to attune to sensory patterns and spatial constraints before their AR design session.

The workshop was structured into four timed segments: (1) a short onboarding to familiarize participants with the tools and interface logic; (2) an ecological attunement phase (AR for both groups, VR for the island group); (3) the modeling and deployment of a situated design intervention; and (4) a post-intervention reflection, both verbal and written.

## 2.4 Data collection

Three complementary data streams were collected:

a. Photographic and Screen-Captured Documentation: During the AR phase, participants captured annotated overlays and

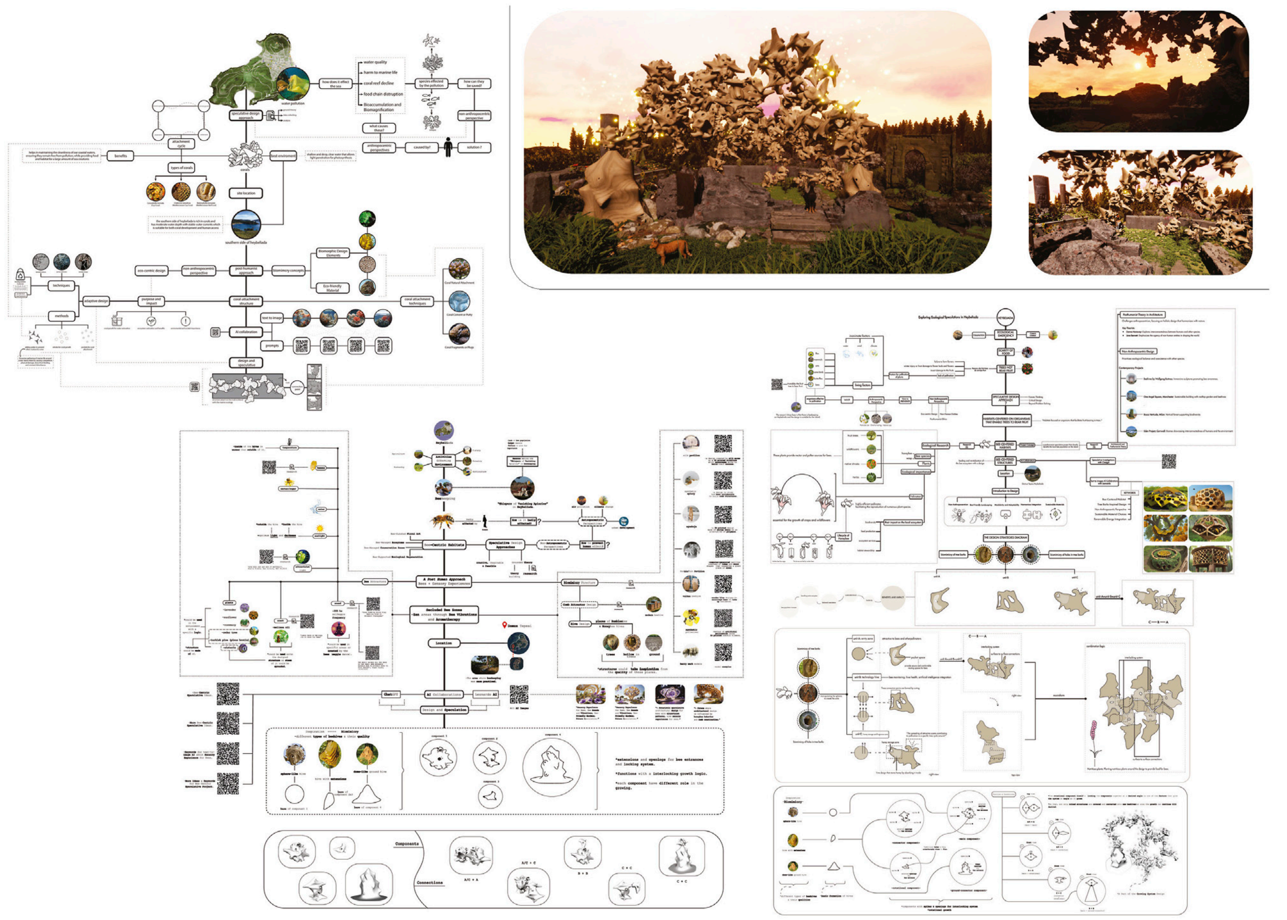

FIGURE 2
Selected participant models developed in Maya, referencing ecological logics such as root systems, marine geometries, and canopy structures. Research models clustered vertically, and island models extended into threshold and ground-level forms.

**TABLE 1 Summary of participant survey responses across sites. Responses reflect ecological attention, spatial friction, and perceived contribution clarity. Values reported as counts out of ten per group.**

| Theme | Courtyard group (n = 10) | Island group (n = 10) |
|---|---|---|
| Reported increased ecological awareness | 8 | 10 |
| Referred to nonhuman actors in reflection | 6 | 9 |
| Experienced sensory or cognitive fatigue | 1 | 6 |
| Noted difficulty navigating interface | 1 | 6 |
| Expressed uncertainty about model visibility | 0 | 5 |
| Used infrastructural anchors in design | 9 | 3 |
| Designed for multispecies integration | 5 | 8 |

real-time deployment screenshots. These were reviewed for site specificity, ecological framing, and formal experimentation. Selected examples are presented in Figure 1.

b. Design Artifacts: Participants submitted final models with brief design narratives describing function, ecological reference, and material intent. Submissions were evaluated for evidence of multispecies design reasoning, formal responsiveness to local spatial cues, and speculative rigor. Selected models are illustrated in Figure 2.
c. Survey and Reflection Responses: After the session, participants completed a structured Likert-scale survey and an open-ended written reflection. These addressed perceived ecological awareness, spatial agency, interface navigation, and authorship concerns. Summary data are presented in Table 1. The full text of

the post-session survey, including Likert-scale items and open-ended prompts, is provided in Supplementary Appendix B.

## 2.5 Data analysis

Design artifacts and reflection responses were analyzed through an inductive, interpretive process grounded in close engagement with the materials produced by participants. Rather than applying a predetermined coding schema, thematic patterns were identified through repeated examination of spatial configurations, ecological references, and descriptive language. The analytic focus centered on how participants situated their interventions in relation to environmental features and how their speculative gestures reflected attention to multispecies presence. This approach was informed by Offenhuber's (2017) conception of autographic traces, understood not as symbols but as situated inscriptions that materialize through spatial action and retain the conditions of their emergence. Such a perspective supports the reading of participant-generated forms as evidence of ecological reasoning embedded within environmental and perceptual constraints. As the study proritized participant-led engagement within real-world settings, the analytical process remained qualitative and context-sensitive rather than comparative or formally codified. Survey data were summarized descriptively, with frequency counts used to identify broad perceptual trends. Visual, verbal, and spatial materials were triangulated to trace relationships between formal strategies, narrative framing, and environmental legibility. No inferential statistical procedures were applied, as the survey data were intended to support qualitative insight through descriptive summary rather than comparative analysis.

# 3 Results

## 3.1 Ecological integration and spatial strategies in design outputs

Participants across both sites produced design interventions that demonstrated varying levels of ecological awareness and multispecies inclusion. In the courtyard setting, most design responses clustered around existing arboreal features. Participants used tree trunks and low canopy areas to anchor modular interventions including branching shade structures, pollinator scaffolds, and bark-integrated shelters. The resulting geometries tended to be vertically oriented and compact, shaped to operate within paved boundaries and formal site circulation patterns.

In contrast, island-based interventions were more spatially diffuse and topologically varied. Participants responded to irregular terrain and open peripheral space with ground-integrated forms, edge-oriented canopies, and floating or semi-submerged habitats. Several models referenced shell structures, branching marine plant forms, or sedimentary layering. These forms were often situated at ecological thresholds—between vegetation and path, or coastline and inland—and showed increased attention to water proximity, avian visibility, and soil surface variation. Maya models from the island group more frequently incorporated asymmetry, ground anchoring, and open circulation.

Figure 2 presents a comparative selection of final design outputs. Each model is shown with its proposed site anchor and intended ecological function. Courtyard outputs reflect structural and canopy-focused logics, while island outputs span a broader range of spatial ecologies.

Participants used Adobe Aero to deploy their models on-site. Screenshots submitted during the AR sessions revealed clear differences in placement strategy. In the courtyard, overlays clustered along the periphery of trees and benches, remaining inside circulation zones. On the island, placements extended into less legible zones, including undergrowth, slope transitions, and open gravel patches. Figure 1 illustrates this contrast in deployment behavior.

## 3.2 Participant feedback—awareness, friction, and contribution clarity

Qualitative and survey-based feedback identified three main outcome areas:

a. Ecological Awareness: Participants across both groups reported heightened environmental sensitivity through MR engagement. Many described the experience as helping them "see species differently" or "notice spaces that weren't designable before." For the courtyard group, this awareness was often associated with trees and fixed site features. In the island group, responses referenced micro-ecologies and ecological thresholds, including shoreline interfaces and undergrowth. Survey responses indicated that 100 percent of island participants and 80 percent of courtyard participants reported increased attention to nonhuman actors due to MR use.
b. Cognitive Load and Interface Navigation: Participants in the island group reported higher sensory and cognitive load, particularly when transitioning between immersive VR using Unreal Engine and mobile AR overlays. Sixty percent described the interface as "disorienting" or "difficult to calibrate" in open terrain. In the courtyard group, only one participant reported similar issues, citing occasional lag in device responsiveness.
c. Perceived Contribution Clarity: Some island participants expressed uncertainty about the visibility and persistence of their contributions within the MR environment. Several described the AR deployment as "temporary" or "unclear whether it would be recorded," particularly in moments of annotation. This concern was absent from the courtyard group, where participants treated the digital overlays primarily as sketch or prototyping tools rather than representational outputs.

# 4 Discussion

This study explored how mixed reality (MR) tools mediate ecological perception and participatory design behavior in two urban contexts with contrasting spatial and environmental properties. Through comparative analysis of design interventions, interface experiences, and post-session reflections, we examine how MR operates not only as a visualization device but as a perceptual infrastructure. The results suggest that MR engagement is strongly shaped by environmental conditions, media configuration, and the ways in which participants interpret spatial texture and nonhuman presence (Fuller, 2005).

## 4.1 MR as situated perceptual infrastructure

Participants used MR tools to deploy speculative ecological interventions that responded to trees, ground surfaces, and canopy openings. However, the quality of spatial engagement differed between sites. In the courtyard, spatial behavior tended to reinforce existing infrastructural alignments, with overlays clustered around fixed anchors. On the island, overlays extended into less legible zones, prompting design that was both formally looser and ecologically more specific. These patterns reflect how MR systems mediate perceptual attention in context-dependent ways.

Rather than offering stable feedback, MR in this study functioned as what De Souza e Silva and Sutko (2009) describe as a locative medium that "performs" space through interaction. Rather than passively visualizing their surroundings, participants interpreted and constructed spatial meaning through bodily movement and material speculation (Dourish, 2006). This aligns with Satchell and Dourish (2009) distinction between interfaces that manage information and those that produce environments. In both cases, MR operated not merely as a carrier of content but as an organizer of perception.

## 4.2 Nonhuman legibility and design friction

The forms produced by participants suggest a mode of design reasoning that exceeds human-centric affordances. On the island, participants responded to root systems, shoreline thresholds, and avian behavior, producing interventions that imagined cohabitation or infrastructural sharing. These responses reflect what Haraway (2016) and Tsing (2015) frame as relational design acts of structuring space not for, but with nonhuman actors (Latour, 1993). While such design gestures remained speculative, they represent a shift from optimization logics toward attentional ones.

However, this perceptual expansion introduced friction. Participants described the island interface as more difficult to navigate and interpret, reporting sensory overload and uncertainty about model visibility. Carter and Egliston (2024) emphasize that MR systems often exclude non-standard bodies and contexts, failing to support users in environments where spatial feedback is ambiguous. In this study, the interface became a threshold condition, exposing both ecological richness and perceptual breakdown (Simondon, 2017). This tension is instructive. Friction is not necessarily a failure. It may indicate that design attention has reached a site of misfit where perceptual assumptions no longer hold and new spatial logics emerge (Hall, 1966; Alexander, 1964; Vardouli, 2024)

## 4.3 Participatory practice and computational ethics

The workshops revealed that spatial participation through MR is shaped by more than tool access. It depends on how environmental complexity, media visibility, and perceptual fatigue intersect. Participants in the courtyard reported ease of use but produced fewer multispecies references. Participants in the island setting created more ecologically layered outputs but also expressed confusion over model persistence and interpretive limits. This contrast aligns with critical work in HCI and design justice, which argues that enabling technologies often conceal their exclusions within smooth interaction (Costanza-Chock, 2020; Egliston and Carter, 2022).

As Foster and Iaione (2022) have argued, the notion of the co-city requires more than open data or feedback loops. It requires tools that can mediate distributed agency between humans, ecologies, and infrastructures (de Waal and de Lange, 2013). MR, as observed in this study, operates within this tension. It can scaffold spatial participation, but only when its perceptual assumptions are matched to the complexity of site and subject.

## 4.4 Toward attentional design methodologies

This study contributes to the development of attentional design methodologies that prioritize perception, friction, and multispecies responsiveness. Rather than treating MR as a neutral enhancement layer, we approach it as a mode of inquiry that conditions how space is made knowable and how nonhuman actors are made perceptible. In doing so, we follow Offenhuber (2017), who suggests that design technologies should trace and surface material conditions, not abstract them.

MR tools in this study were used not to simulate ideal futures but to engage existing ecological misalignments. The speculative forms produced by participants were not solutions but probes—material arguments for how bodies, species, and environments might co-configure shared space (Grosz, 2001). As Barad (2003) reminds us, interaction is not a matter of representation but of intra-action, where subjects and objects emerge together through practice (Pickering, 1995). In this context, MR becomes a spatial practice of negotiation, not display.

The observations presented in this study are grounded in two ecologically distinct and spatially specific urban sites, as well as a design-focused participant group. While the research does not aim to generate statistically generalizable claims, it offers transferable insights into how MR systems shape environmental legibility, spatial authorship, and perceptual attention. The situated nature of the workshops is not a limitation but a condition of the knowledge they produce. These findings may inform future applications of MR in different urban morphologies, particularly where perceptual infrastructures are entangled with ecological sensitivity, design agency, or civic participation. Further inquiry across diverse cohorts and spatial regimes could extend this line of investigation.

## 5 Conclusion

This study examined how mixed reality (MR) interfaces mediate ecological awareness and design agency in spatially and environmentally distinct urban settings. By comparing participant interactions across a structured courtyard and an open-edge island microzone, the research revealed how MR tools shape perception, guide spatial attention, and enable multispecies reasoning through embodied engagement. Rather than functioning as neutral extensions of design intent, MR systems operated as contingent perceptual infrastructures whose effectiveness was conditioned by environmental legibility, cognitive load, and the capacity of users to interpret ambiguous feedback.

In both sites, participants employed MR to generate speculative ecological interventions that reflected varying degrees of spatial sensitivity, material responsiveness, and nonhuman consideration. Design behaviors in the courtyard gravitated toward infrastructural anchors and formal legibility, while the island setting elicited more experimental, threshold-based interventions that challenged conventional distinctions between body, site, and species. Participants' reflections indicated that MR engagement affected not only what was seen, but how space was sensed, navigated, and imagined.

These findings support a growing body of work that approaches digital tools not as static media but as dynamic infrastructures for environmental cognition. The study contributes to attentional design methodologies by foregrounding friction, perceptual misalignment, and site-specific variation as conditions through which ecological responsiveness can emerge. Future research may build on this approach by expanding the range of environmental typologies tested, refining the sensory calibration of MR systems, and deepening cross-disciplinary collaboration between design, cognitive science, and ecological theory. As urban environments become more entangled with technological and ecological complexity, the ability to design tools that support situated, multispecies, and perceptually rich engagement will remain a central challenge for participatory design.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Ethics statement

Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

## Author contributions

KK: Investigation, Writing – review and editing, Funding acquisition, Software, Conceptualization, Writing – original draft, Resources, Project administration, Validation, Methodology, Visualization, Formal Analysis, Data curation, Supervision. EG: Writing – review and editing, Supervision.

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The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/frvir.2025.1628312/full#supplementary-material

## References

Albrecht, G. (2017). "Solastalgia and the new mourning," in *Mourning nature: hope at the heart of ecological loss and grief*. Editor A. Cunsolo and M. Landman (Montreal: McGill-Queen's University Press), 292–315.

Alexander, C. (1964). *Notes on the synthesis of form*. Harvard University Press.

Barad, K. (2003). Posthumanist performativity: toward an understanding of how matter comes to matter. *Signs* 28 (3), 801–831. doi:10.1086/345321

Beatley, T., and Newman, P. (2013). Biophilic cities are sustainable, resilient cities. *Sustainability* 5 (8), 3328–3345. doi:10.3390/su5083328

Carter, M., and Egliston, B. (2024). Fantasies of virtual reality: untangling fiction, fact, and threat. Cambridge, Massachusetts: The MIT Press.

Costanza-Chock, S. (2020). *Design justice: community-led practices to build the worlds we need*. MIT Press.

Davis, A., and Wagner, B. (2024). Understanding the role of ‘sense of place’ in the production and consumption of innovation districts. *Innov*. doi:10.1080/14479338.2024.2363258

de Souza e Silva, A., and Sutko, D. M. (2009). *Digital cityscapes: merging digital and urban playspaces*. Peter Lang.

de Waal, M., and de Lange, M. (2013). Owning the city: new media and citizen engagement in urban design. *First Monday* 18 (11). doi:10.5210/fm.v18i11.4954

Dourish, P. (2006). “Re-space-ing place: “place” and “space” ten years on,” in *Proceedings of CSCW ’06*, 299–308.

Egliston, B., and Carter, M. (2022). The material politics of mobile virtual reality: Oculus, data, and the technics of sensemaking. *Convergence: Intern. J. Res. New Media Tech.* 28 (2), 595–610. doi:10.1177/13548565211072342

Foster, S., and Iaione, C. (2022). *Co-cities: Innovative transitions toward just and self-sustaining communities*. MIT Press.

Fuller, M. (2005). *Media ecologies: materialist energies in art and technoculture*. MIT Press.

Grosz, E. (2001). *Architecture from the outside: essays on virtual and real space*. MIT Press.

Hall, E. T. (1966). *The hidden dimension*. Doubleday.

Haraway, D. J. (2016). *Staying with the trouble: making kin in the chthulucene*. Durham, NC: Duke University Press.

Hinchliffe, S., and Whatmore, S. (2006). Living cities: towards a politics of conviviality. *Sci. As Cult.* 15 (2), 123–138. doi:10.1080/09505430600707988

Ingold, T. (2011). *Being alive: essays on movement, knowledge and description*. London: Routledge.

Klopfer, E., and Squire, K. (2008). Environmental detectives: the development of an augmented reality platform for environmental simulations. *Educ. Technol. Res. Dev.* 56 (2), 203–228. doi:10.1007/s11423-007-9037-6

Latour, B. (1993). *We have never been modern*. Harvard University Press.

Manzini, E. (2015). *Design, when everybody designs: an introduction to design for social innovation*. MIT Press.

Milovanovic, J., Moreau, G., Siret, D., and Miguet, F. (2017). “Virtual and Augmented Reality in Architectural Design and Education“, 17th International Conference, CAAD Futures 2017. Editors G. Çağdaş, M. Özkar, L. F. Gül, and E. Gürer (Istanbul, Turkey: Istanbul Technical University).

Offenhuber, D. (2017). “Autographic design: evidence and narrative in the data city,” in *Graph vision: visualizing information in design practices*. Editors T. Vardouli and C. Buehler (MIT Press), 159–179.

Parisi, L. (2013). *Contagious architecture: computation, aesthetics, and space*. MIT Press.

Pickering, A. (1995). *The mangle of practice: Time, agency, and science*. University of Chicago Press.

Satchell, C., and Dourish, P. (2009). “Beyond the user: use and non-use in HCI,” in *Proceedings of OzCHI ’09*, 9–16.

Simondon, G. (2017). On the mode of existence of technical objects. Editor C. Malaspina and J. Rogove, Trans. (Minneapolis, Minnesota: Univocal Publishing, University of Minnesota Press).

Suchman, L. (2007). *Human–machine reconfigurations: plans and situated actions*. Cambridge University Press.

Tsing, A. L. (2015). *The mushroom at the end of the world: on the possibility of life in capitalist ruins*. Princeton University Press.

Vardouli, T. (2024). Graph vision: digital architecture’s skeletons. The MIT Press. doi:10.7551/mitpress/14229.001.0001

Whatmore, S. (2002). *Hybrid geographies: natures cultures spaces*. London: Sage.

Wolch, J. R. (2007). Green urban worlds. *Ann. Assoc. Am. Geogr.* 97 (2), 373–384. doi:10.1111/j.1467-8306.2007.00543.x

Zylinska, J. (2020). *The perception machine: our photographic future between the eye and AI*. MIT Press.