MULTI-SPECIES AND MULTI-SCALAR URBAN TOPOLOGIES (PREPRINT)

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KEYWORDS

Urban Ecosystems, Multi-species, Multi-scalar, Computational Design, Advanced Manufacturing, Cyber-physical Systems.

ABSTRACT

Over half of the world's population lives in urban areas, with an increase to 68% by 2050 (UN report, 2018) and their ecosystems are in need of repair and restoration. Hence, understanding urban ecosystems across different scales and knowledge domains is vital to global sustainability. Presented research focuses on multispecies interactions, in the context of shifting environmental conditions due to climate change. It introduces adaptive strategies that integrate landscapes, built environments, and multi-species infrastructures. In this work, strategies and knowledge domains of sustainability, ecology and species diversity are combined with architecture, computational design, advanced manufacturing, and material systems performance. By investigating multi-species across scales ranging from micro to macro and by designing new topologies, urban ecosystems are established that are serving equally all species. In this context, computational design, simulation, analysis, and advanced manufacturing allow evaluation, understanding, and forecasting trends and consequences of connected impacts across multiple knowledge domains and scales as well as developing and operating sustainable ecosystems.

1 INTRODUCTION

Today, some 56% of the world's human population – 4.4 billion – live in cities. By 2050, with the urban population more than doubling its current size, nearly 7 of 10 humans in the world will live in cities (Worldbank 2020). In many of these cities, the overwhelming human impact on the environment implies that natural environments offering habitats for species other than humans (i.e., plants and animals) are threatened. This impacts not only those species who have long made their home in urban spaces, but those who take refuge there as their habitats are destroyed or climate conditions make them uninhabitable. Closed surfaces, remnant vegetation and degraded systems are in need of repair and restoration, with an understanding of the fragile relationships between animals, plants, and humans. As a consequence, understanding urban ecosystems across different scales and knowledge domains is vital to global sustainability for humans and more-than-humans - the plants and animals with whom humans are cohabiting and whose existences are intricately linked to theirs.

The research discussed here takes the form of a whitepaper (coupled with the co-creation call) and presents an initial framework for developing just and effective responses to the devastating impact that contemporary western forms of human life and urban design are having on more-than-human worlds. These impacts are exacerbated by the pressure that global heating is putting on the habitats of all beings. Adopting a multispecies justice perspective, implies that design for the future must include natural urban processes, be attentive to more-than-human relationships, and be capable of supporting biodiversity in urban ecosystems (Celermajer et al. 2021a).

Recent research has developed manufacturing for species using mycelium or biopolymers (Colmo 2020, Lim 2021, Oskam et.al 2022), marine ecosystems such as corals and artificial reefs (Dunn 2019, Lange 2020, Vogler 2022) or urban simulations (White 2019) but ecological, terrestrial and wide-scope species simulations and design to manufacture methods require further advancement. This paper presents a multidisciplinary scoping and joint approach for developing the background of and framework for infrastructures i.e., scaffolds as integrative ecologies across multi-species and multi-scales in urban settings, from dense inner cities to vast and regimented landscapes of suburbia. It reports on case studies for bio-strategies of renaturing and rewilding the urban structure, planning strategies to support pollination, seeding, and animal interactions. These case studies demonstrate opportunities for reconfiguring spaces through customised components, structures, and pods that actively support natural processes by way of using advanced manufacturing and robotic production for hybrid, multi-material, scalable, customisable and adaptable solutions.

Consequently, this paper aims to open a discourse between the different disciplines of environmental sciences, biology, architecture and design, computation and advanced manufacturing and fabrication. The goal is to contribute to, give prompts for and enable dialogue towards initiating collaboration for increased agency of the more-than-human, and for more equitable and just practices in an anthropocentric contemporary culture. The aim is to develop profoundly different approaches to how humans regard and interact with nature that ultimately can contribute to making future cities and habitats more liveable for all, more equitable and relational between multiple species, and more resilient by way of linking process-driven and time-based aspects through computational systems.

In the following, the paper presents in Section 2 distinct lenses that contribute to framing the multidisciplinary discourse. Section 3 provides a number of case studies that are geared towards designing for and designing with multiple species in cohabitative environments. Section 4 discusses results, limitations and challenges that arise from the case studies and introduces a preliminary framework for continued research collaborations and further investigations. Section 5 concludes with an outlook to future research.

2 BACKGROUND

Presented research investigates landscapes, built environments and species infrastructures in pursuit of a collaborative approach that performs as a scaffold for protecting and sustaining fragile ecosystems. It explores how contaminated, waste-landed and unlivable urban scapes can be regenerated and nurtured by employing novel approaches using currently available digital systems, including photogrammetry, robotic manufacturing, and cyber-physical systems. To highlight the contributing factors that interplay and which are brought together, a number of disciplinary lenses are discussed in the following, including an approach to multispecies and more-than-humans (Subsection 2.1); a species interrelationships and ecological frame overview (Subsection 2.2); and an approach towards adopting computation (3D modelling, simulation and analysis) and cyber-physical approaches (involving robotic and sensor-actuator systems) for a better understanding of and engagement with the environment as ‘Umwelt’ and ecological system (Subsection 2.3).

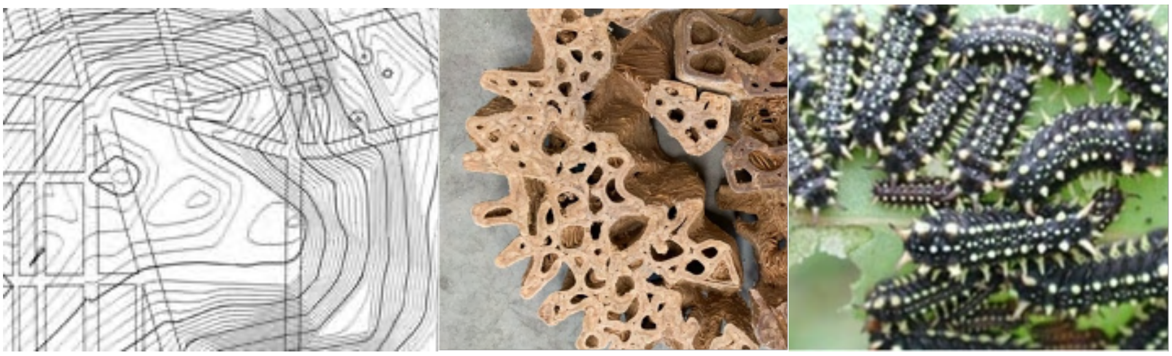

Figure 1: Scale-changes for computational evaluation and prototyping: 3D Topographical assessment[1] for macro-overview (left), baseline 3D robotic print transfer for habitat creation (seedpods, water retention, small-scale animal occupancy, mid), and plant-species relationships for consideration and support in habitats (right).

2.1 An Approach: Multispecies and More-than-Human Justice

As the devastating and highly uneven impacts of climate change and the intensification of its trajectory become more evident, questions about the foundational values that underpin all institutional design become more pressing. In this context, there is an increasing number of calls for, and experiments in the inclusion of the interests of the more-than-human in political and legal institutions (Donaldson and Kymlicka, 2016; Eckersley 1992; Meijer, 2019; Schlosberg, 2007; Stengers, 2005; Tanasescu, 2016). Critical to such calls is a recognition that the approach of the laws and policies, which have been enacted and adopted to purportedly protect animals other than humans and the environment are critically inadequate insofar as they continue to position beings other than humans as defeasible side-constraints, inevitably discounted when short term human, and in particular economic interests are invoked. The result, as powerfully illustrated by the ways in which the *Environmental Protection and Biodiversity Conservation Act* in Australia has provided pretext for untrammelled destruction of environments and habitats (Celermajer et al. 2021b), is that so-called environmental or animal protection legitimates systemic violence of the more-than-human. This recognition of the insufficiency of an ethos of modification, where humans continue to determine the extent to which the interests of others will shape decisions about urban design and infrastructure, is also being taken up in the fields of architecture and urban design (Fieuw et al., 2022; Gordon and Roudavski 2021).

The idea of multispecies justice seeks to take up this more foundational challenge to the human exceptionalism at the core of institutional design by insisting that beings other than humans ought to be considered *subjects* of justice. The implication is two fold. First, insofar as they count as justice claims, their interests cannot be discounted within a utilitarian calculus but must be included in decision making about institutional design. Second, and more radically, they have a right to representation in decision-making processes, either through some form of carefully designed proxy representation, or more directly. Critically, multispecies justice is not motivated by an extensionist logic, whereby humans come to appreciate that other beings also have capacities that have been considered the basis for humans' moral considerability. Rather, eschewing this more subtle form of anthropocentrism, it is motivated first by an acknowledgement of the intrinsic value of the myriad ways of being beyond the human, and second by a belated recognition of the entanglement of human

[1] Link to MIT project: https://web.mit.edu/wplp/course/f96stud/place/urbannat/dwg1.jpg

and more-than-human worlds. In other words, the very idea of human centred design that excludes or renders peripheral questions of impact on the more-than-human is absurd.

2.2 Species and Ecological Systems

Concerns over global biodiversity declines have historically focused on charismatic and popular species who have been identified at risk of extinction (Hunter & Gibbs, 2007). While these iconic species have often galvanised the wider community to advocate for action, there is widespread acceptance that ecologists need to promote bigger picture and more inclusive approaches to managing biodiversity (Keith 2015). Identifying actions that target higher levels of biological organisation such as ecosystems and ecological communities is central to generating better conservation outcomes (Bland et al. 2019).

The recognition that habitat loss and degradation are major drivers behind the current sixth mass extinction event has led to extensive efforts to arrest declines through habitat restoration and remediation (Bastin et al., 2019) . Many of these actions have focused on landscape level large scale replanting and reforestation schemes, using a restoration ecology framework that is geared towards a surprisingly diverse array of goals and endpoints (Higgs et al. 2018) . These range from the increasingly less popular return to a historical state, returning to some current existing reference state, or simply increasing overall coverage of vegetation in areas that have been significantly altered for by humans through agriculture, urbanisation, and extractive activities (Hobbs 2007).

Cities are typically considered to be hostile places for biodiversity and nature, possibly unfairly (Spotswood et al., 2021). While it may be counter-intuitive to focus limited resources on concerns over biodiversity in cities, there is an urgent need to identify how to plan, build and manage nature, nature connections, and biodiversity to make cities function sustainably (Taylor & Hochuli, 2015). This argument can be prosecuted from multiple perspectives; from the traditional perspective of conservation biologists, there is a surprisingly large group of animals and plants that are protected under threatened species legislations in cities (Soanes & Lentini 2019). For those adopting a more utilitarian perspective there is an unambiguous link between greenspace, nature, and the liveability of cities for humans (Taylor et al. 2018; Taylor & Hochuli 2015)

In addition to extensive management efforts to increase the extent of green space in cities, a range of small-scale interventions targeting specific animals and plants have also been advocated (Watchorn et al., 2022). These include the provision of nestboxes to provide habitat for species that rely on hollows in old and dead trees, which are a major limiting resource in cities (Le Roux et al. 2016), or the installation of bee hotels that provide nesting sites for a range of native bees whose populations are limited by the lack of locations (MacIvor & Packer 2015) . While these interventions are actively promoted, there is little evidence to suggest that they are effective in providing habitat for target species for both nest boxes and bee hotels, with many ecologists concerned that their efficacy has been significantly overstated (Lindenmayer et al. 2017). As with many replanting efforts, the success of restoration actions is often measured by the actions undertaken (numbers of trees planted, number boxes installed, etc.) rather than the ecological outcomes achieved.

Cities provide an ideal opportunity to explore creative and innovative solutions to providing habitats for biodiversity. They are typically conceptualised as novel ecosystems, supporting an assemblage of animals and plants without a rich evolutionary history of coexisting. In addition to supporting a range of generalist and opportunistic native animals and plants, much fauna and flora in urban ecosystems is non-native, with many species maligned as pests and weeds. Nevertheless, the growing acceptance that promoting and supporting biodiversity (regardless of its origins) in cities through effective habitat management and creation, is central to the sustainability of future cities.

2.3 Environment and 'Umwelt': Computation for Ecology

For those concerned with multispecies justice and specifically the cessation of violence against the more-than-human, paying attention to others' lives and experiences and including their perspectives in how humans think about and plan interventions in environments is a critical first step. Even if humans are ethically committed to attending to others, however, given the massive amount of diverse information, this represents a serious challenge. Computational design allows for seamless integration of captured data on topographies, (urban) landscapes and environments that so become available for simulation processes, evaluation, and potentially remediation, reconstruction or support through ecological interventions on many different scales. This includes scale shifts through computational design and advanced manufacturing that enable a) collaboration between disciplines by changing the lens or focus point between macro and micro (for example, from frog to birdseye view) or rather, understanding ecological impacts from the level of a bug to the level of dynamic changes in the landscape.

In a larger sense, this facilitates understanding the environment - and constellations and partnerships within this environment - through various lenses - perhaps not becoming the bird, the frog, or the valley, but exploring such viewpoints (in a digital realm) and becoming more capable of including such perspectives. Computation can support an 'ontology and epistemology of entanglement'; whereby the interests of multiple agents, of multiple species, could be taken into consideration - not from an anthropocentric viewpoint, where humans represent others, but potentially as 'co-designers'.

Figure 2. Computational codes/scripts that demonstrate mathematical/universal principles that variably can underlie natural phenomena, shapes and patterns, morphologies, or behaviours > scale-less codes that can be understood to model and bridge between species [x, deleted for review].

In order to be able to do so, various aspects of the discrete physical environments have to be considered from changing microclimates to dynamic interactions, etc. Within digital environments, the flattening of hierarchies is allowing multiple perspectives and criteria to be closely surveyed, and customised designs to be tested, evaluated, and optimised before irreversible implementations into real environments are created. Cycles of times, seasons and various changes can be orchestrated, tested and potentially understood, then possible solutions can be modelled over time in order to approximate the impacts on and experiences for other beings. This raises ethical questions regarding (a) which perspectives and experiences can and should be prioritised and (b) which agencies of the more-than-human can be supported to make ecological systems sustainable?

Significantly, the shift of perspective through computation allows architects and planners to design with and for more-than-human 'clients' by pursuing forms and conditions under which these other beings can flourish. By connecting current technologies and approaches involving (1) data capture (scanning and photogrammetry), (2) detailed trialling in digital environments through 3D modelling and scripting (Rhino, Grasshopper, etc.) with evaluation and optimisation across various criteria, (3) advanced manufacturing (3D printing, robotics, etc.), and (4) sensor-actuator integration, new environments are created and sustainable ecosystems are potentially established.

3 CASE STUDIES

The multidisciplinary discourse framed so far is explored in a number of case studies that are geared towards designing for and designing with multiple species in cohabitative environments. The case studies presented here discuss scale shifts across interventions, from discrete small-scale, morphological prototyping adapted to context (section 3.1); to prototyping 'kick-starters' for residual spaces (section 3.2); to large-scale shaping of topographies (section 3.3).

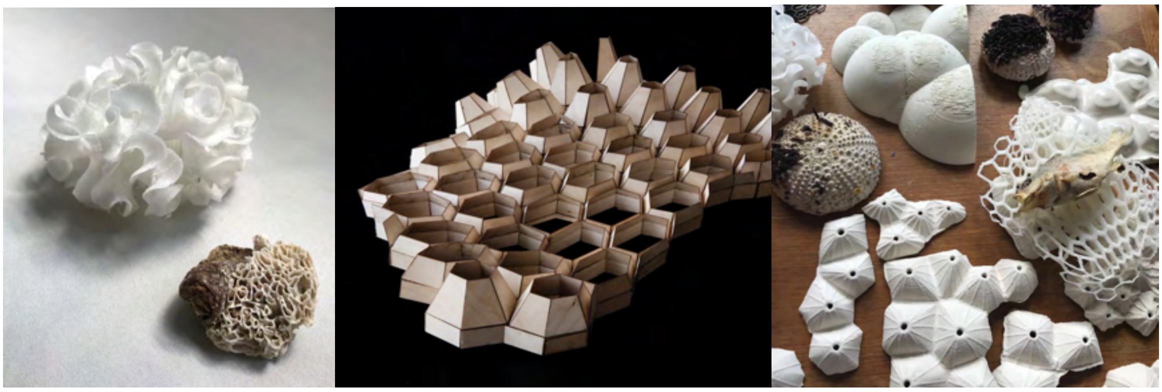

Figure.3.1.1: Sponge/brain Gaussian structures (left), extrinsically informed hexagonal modules (middle), natural and artificial morphologies juxtaposed/combined (right)

3.1 Case Study 1: Colonies and Colonisers with Shared Mathematical Principles

The organisational/ constructive logic of parts for singular, yet relational networks in complex and integrated natural systems can provide further insights into the interaction of multiple entities, including dynamic temporal formations of terrestrial animals, plants, and inanimate particles of sounds, light, currents that define their environment. Similar to biological systems, mathematical codes can respond and adapt to environmental stresses and dynamic loadings, to contextual extrinsic force flows, to changing data flows. Codes adopted for forms, concepts, and design systems then respond in evolution, developing continuously through degrees of redundancy, optimisation, and complexity, in material and structure, and over time. They can inform structure and skin, behaviour and interaction of built environments, and thus act as informational drivers, as 'design machines' for a built environment that shifts from surface to volume and system. Deployed as the logic of a mathematical framework or procedural approach in computational design, a shift takes place from result to protocol, which relies on explicit rules that produce multitudes of dynamic systems, patterns, and constructs.

In this first case study, multiple heterogeneous systems interact whereby an organism formed of singularities (the coral or barnacle) contributes to forming multiples as a larger ecosystem (the colony). Within this natural phenomenon, the singularity of individuals and diversity in multiple codes, different life forms, and collectives of swarms play out as cohabitation. Its structures, growth patterns, and behaviour is dynamic. *Colony* indicates correlation and interchanges between numerous and different forms of animate and inanimate, mobile and stationary, temporal and generational dynamic systems that evolve continuously. The colony changes with shifts in intrinsic and extrinsic forces, with a choreography of balanced systems following, responding, and adapting by actuating inscribed mathematical, adaptable—and thus evolutionary—codes. In the colony, it is not the one, but the many that count. The colony's mathematical codes and their interacting and integrated principles and systems can constitute a reference archive that expands the development and application of shapes, patterns, and morphological variations towards the totality of an environment. And while many codes are 'shared' between diverse entities, no singular code is the exclusive driver for formations; on the contrary, apart from individual organisms, most species employ complex combinatory sets of code for their growth and development.

Figure.3.1.2: Script coded as reactive to contextual conditions (left), robotic milling for slip casting (middle), distribution of sensors in cavities (right)

3.2 Case Study 2: Designing Bio-Cyber-Physical Ecosystems

Considering that current architectural interventions increasingly emerge from the interaction of human and non-human i.e., software and hardware agents (Green 2016; Bier 2018; Hensel and Bier, 2022) and they potentially initiate and activate bio-cyber-physical (BcP) environments that intertwine natural and artificial worlds (Bier et al. 2022), the second case study envisions in this context all actors, human and non-human as contributors to the emergence of unprecedented BcP ecosystems.

Cyber-physical approaches have a long history going back to the 70s when the intersection between digital technologies and physical spatial experience started to be explored (Negroponte 1970). Those concepts have been advanced towards small scale architectural environments since the 90s (Zelkha et al. 1998; Fox and Kemp 2009) and more recently extended towards incorporating cities and landscapes (Deakin 2013). Meanwhile, various projects involving artificial reefs and 3D printed scaffolding for plants or microorganisms (Gautier-Debernardi et al. 2017, Hamman 2015) have shown that eco-friendly solutions can meet the needs for increasing biodiversity in various environments.

Fig. 3.2.1: Assembled [x, blinded for review]] (left) placed in a residual space (right)

In this second case study, the potential of a robotically formed and cyber physically integrated ecosystem intertwines natural and artificial worlds [x at x, blinded for review]. The project investigates such potential by inserting small scale interventions of ±80/70/60 cm in residual urban spaces. The [x] act as seeds for repopulating residual spaces (Fig. 3.2.1) that are resulting from deindustrialization and various socio-economic shifts. They offer opportunities for various animal and plant species to escape industrialised agricultural landscapes that are overusing fertilisers and pesticides. These ‘sanctuaries’ have the potential to help restore biodiversity while inviting neighbours and passers-by to participate in the co-creation process supported by cyber-physical systems and data-driven design to robotic production and operation processes.

Fig.3.2.2: Robotic 3D printing with wood-based biopolymer (left), distribution of sensors in cavities (middle), and components (right)

With robotic fabrication processes focused on customised material deposition, the integration of sensors into the [x] (Fig. 3.2.2) enables life data feedback. Sensors here monitor the microclimates with respect to temperature, humidity, presence of humans and animals and inform neighbours and passers-by via an app about the need to water the inserts or move them to another spot. By engaging neighbours and passers-by in a ‘carrying’ relationship with the [x] and the larger residual space the co-creation of what can be described as urban garden is initiated. When imbued with Artificial Intelligence

(AI), the networked modules rely on learning capacities to predict moments – depending on the patterns of human and non-human activities around them – when opportunities arise for interaction with the evolving nature (vegetations, insects, animals, etc.) and humans.

3.3 Case Study 3: Counteracting Homogeneity - Foundational Probes for Modifications of Landscape and Plantation

The third case study responds to a degraded site, a former banana farm as precedent of industrial remnants that has undergone violent swings in ecology at the hands of agriculture and development. Declared 'disturbed land' (Morand 1996), the site was formed by volcanic activity 23 million years ago and was rich in volcanic soil. It is now degraded by agricultural development and left desolate due to pesticides and stripping of vegetation, with friable topsoil being eroded and leaving a thin, loose layer of unconsolidated particles. The case study focuses on reparation and regeneration from a base level (soil, retaining walls) and support relocation and inhabitation of multispecies and the development of resilient ecosystems (by introducing seeds, plants). The study investigates this across multiple dimensions and levels. In a first phase, a species and habitat mapping is conducted via photogrammetry, surveillance and recording of movement and species data. The land studies seek to describe the natural topography and its changes, identify erosion tracts and weather conditions, with the goal to support patterns and terrestrial formations through direct robotic additive processes in situ, directed towards altering the terrains to serve a multitude of species. The research engages directly at a 1:1 scale with the natural properties of the site (its soil, plants and animals) by adding and strengthening its characteristics (printing clay composites, distributing seed and plant packages).

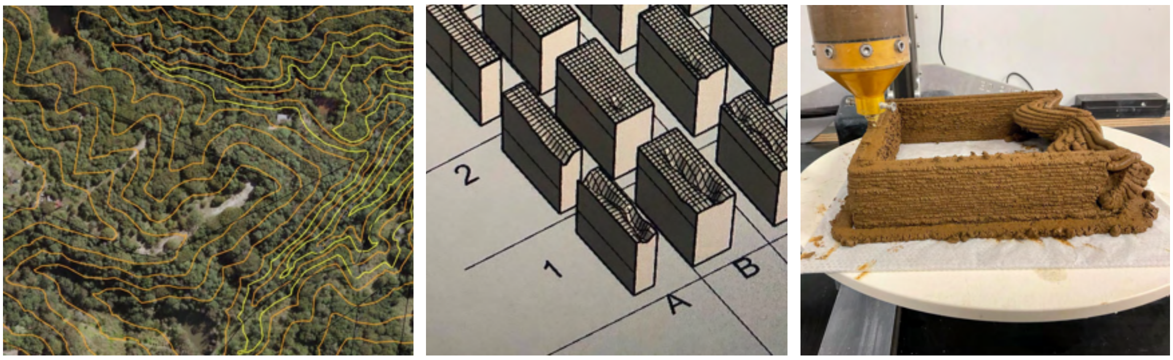

Figure 3.3: Existing conditions on site (left), topography and sectional approach for 3D print segments to be inserted (mid), 3D print technology with customised soil/clay aggregate mixes, with sections to be directly integrated in existing soil strata..

Through initial prototypes, 3D clay/ soil printing is explored to improve soil functionality by constructing new topographical strata and areas, and embedding mycorrhizal fungi within the soil, emulating a ridge sequence to capture hydro eroded soil and provide means for regeneration of native species. Drawing upon research by Barnes et al. (2022) around active soil structures and techniques for additive manufacturing using soil by Arrieta-Escobar et al. (2020), soil from the site in Northern New South Wales (NSW) was mixed at a ratio of 5:1 with water to print an experimental sample for insertion back into the site. Using material extrusion methods the local soil was mixed with mycorrhizal fungi, wedged and compacted into the printer cartridge and extruded through a 0.6 mm nozzle at a printing speed of 350% with an extrusion rate of 100%. The resultant scaffold of ±250/200/40 mm with the layers of the extruded soil creating ridges that are intended to allow for the growth of mycelia and resultant plant life, potentially offers refuge to other species. Without reinforcement in the form of a binding agent or fibres included within the printing the scaffold subsequently dissolved within the landscape following a solid downpour.

The question if the manipulation of topography performed by the continuous robot action allows the creation of alternative landscapes over long durations of time, with continuous data feedback on environmental and ecological processes will be addressed by prototyping and with the site offering a test bed for investigating how to return organic material to the soil to support growth and animal inhabitation. The question of how the landscape ‘communicates’ with the robots to ensure its own evolution and safety can be addressed by establishing feedback loops via sensor networks.

4 DISCUSSION

Through the presented case studies, the research opens a discourse on architecture, ecology, data-driven design, advanced fabrication and human/ more-than-human/ non-human interaction with an understanding and exploration of complex ecosystems through matter, space, time, and behaviour.

To date, the idea of multispecies justice has been an ethical challenge, calling on humans to include beings other than humans as subjects whose lives and flourishing have claims of justice on how we live and what we do. It is, though, also a practical challenge. The discounting of other species has largely been the result of their being positioned as a resource for human use and extraction, but it is also a result of the difficulties involved in apprehending how the world occurs to them. Plants and animals have experiences of the world that are radically different to those of humans. Not only do they sense differently and possess different senses, but space and time occur to them in very different ways (Yong 2022).

In approaching the task of transforming urban environments so that they can afford hospitable environments, not only for humans, but for the others with whom humans are coming to appreciate their lives entangled, it is critical to learn how to include other species perspectives into imagining, projecting, and ordering of spaces, while taking a range of timescales and rhythms into account. It is here that computational design, robotics, and cyber-physical systems with their capacity for integrating vast amounts of data across different scales and processes, can assist.

Presented case studies attempt to advance socio-technical interventions made in natural or urban environments to improve biodiversity by exploiting the potential of computational and robotic approaches that involve sensor-actuator networks. They link natural and artificial environments and intertwine human and non-human agencies, where use of space is not anymore dominated by one or the other but is shared. Importantly, the case studies show opportunities for experiments, with scope to set up small-scale studies targeting ecosystems populated by agents such as inverts, fungi, and bacteria that are building blocks for multitudes of small interventions replicable in many places. There is a large potential for short term small-scale interventions in dense urban areas and long-term studies on larger contaminated sites in urban and rural areas.

5 CONCLUSION AND FUTURE WORK

At this point, what is critical is the willingness to experiment. Such experimentation requires the integration of a range of knowledge domains stemming from various disciplines (ethology, ecology, architecture and robotics) and more-than-human ideologies. By bringing together a range of experts and synthesising their knowledge, computational models are easily created by integrating various knowledge fields about a range of species inhabiting a particular area. This facilitates (a) simulation of design options and their potential impact on various beings and (b) prototyping and testing, while scaling up is the next step.

In this context, the novel opportunities offered by cybernetic social-ecological systems and their ability to identify correlations between the evolving nature, weather variables, and actions of humans in order to predict moments of opportune interaction and to promote them through open access platforms and mobile applications render human and non-human agents (either natural of artificial) as co-creators of processes and events.

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