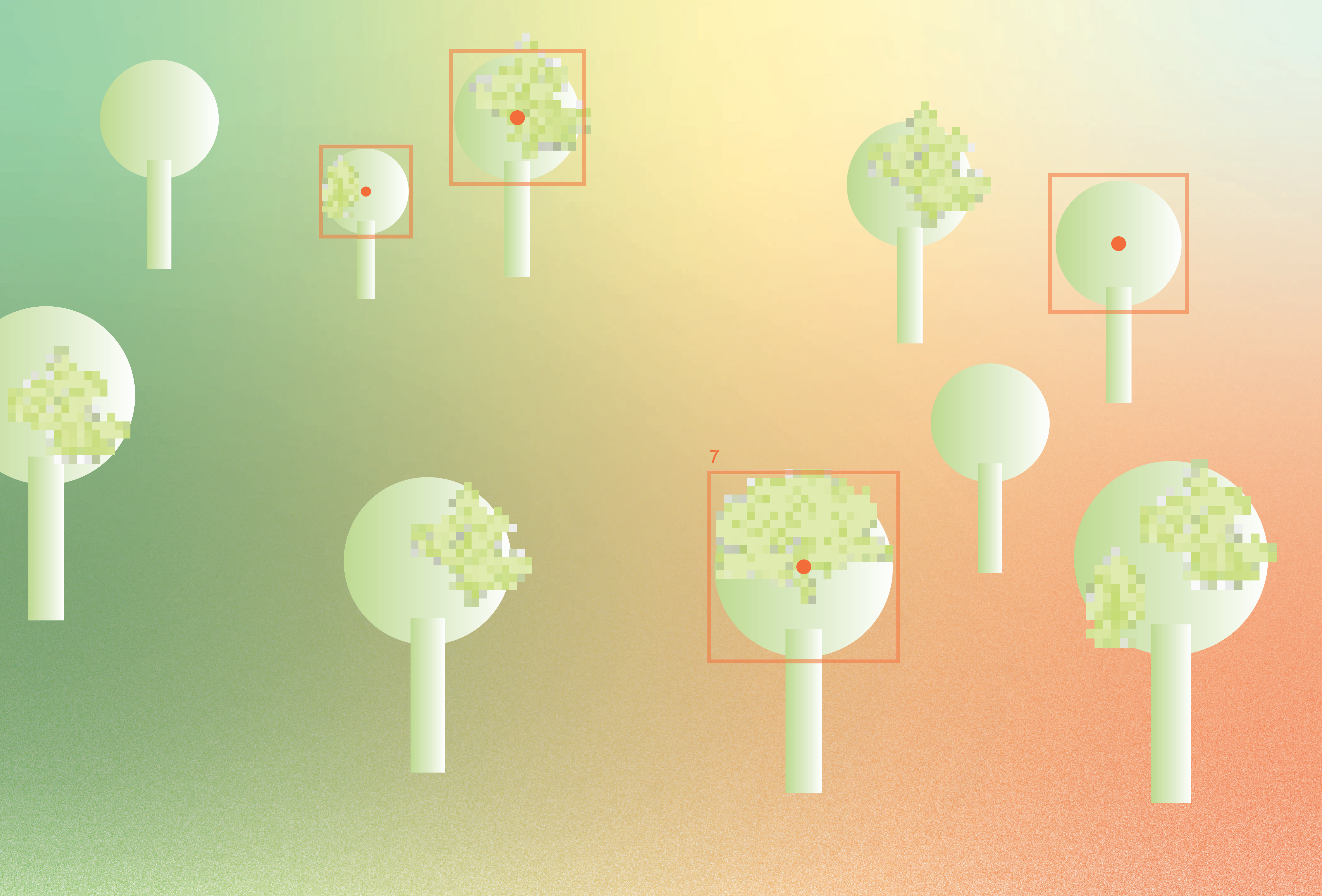
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ECO-URBAN FUTURES

A MORE-THAN-HUMAN APPROACH TO MULTI-AGENT SIMULATION FOR THE DIGITAL TWIN OF URBAN FORESTS

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INTRODUCTION

Humans are now recasting urban forests as infrastructures with the aid of digital technologies. Urban forests' ecosystem services, such as carbon sequestration, urban heat reduction, and water retention, are seen as solutions to manage and mitigate environmental change. Termed as smart urban forest, this particular mode of governance utilizes data generated by digital technologies to support, enhance, and influence urban forest policies (Prebble et al., 2021). Despite its positive prospects, however, the digital twin based on anthropocentric perspectives and values poses a risk of selectively consolidating futures that are "good" for humans, which do not guarantee the same well-being for nonhuman species inhabiting the forest. Acknowledging that humans inevitably coexist with other forms of life, it is imperative to seek ways to reimagine healthier futures for us-with-the-forest.

Gabrys, J. (2020). Experimental forest with sensors [Photograph]. Smart forest and data practices: From the Internet of Trees to planetary governance. https://doi.org/10.1177/20539517209048

PROJECT STAKEHOLDERS

Lucidminds, an R&D collective that provides impact ventures and solutions against societal challenges, wants to expand its Green Urban Scenarios framework (GUS) by including multi-species in its computational model. GUS is a digital twin representation and simulation of urban forests and their impact. This is powered by agent-based modeling which simulates urban forest's growth and their future ecosystem services under varying weather conditions, maintenance regimes, species compositions, spatial distributions, and exposures to diseases.

PROBLEM STATEMENT

Digital twin simulation generates different future scenarios depending on how they capture reality. However, the underlying ontology and epistemology of these digital forests are rarely questioned, often filtering out the vibrant multi-species realities. In the long term, this can threaten the health of the forest by favoring certain trees based on their species, position in relation to boundaries, estimated 'useful life', ecosystem services, or monetary values. The interdependencies among trees, humans, and multispecies calls for smart urban forests to adopt a new approach to listening to and speaking with forests.

RESEARCH QUESTIONS

1. How can design researchers approach forest data in a way that is inclusive and respectful of the interdependencies among trees, humans, and other species?
2. How can design researchers decenter themselves when collecting, making sense of, and modeling the digital twin simulation of an urban forest?
3. What kinds of more-than-human data are present in the urban forest and what do they tell about the wellbeing of the forest?

DESIGN GOAL

The project aims to lay the groundwork for more-than-human forest governance where policymakers, experts, and citizens can rethink healthy future(s) for us-with-the-forest using forest data. This will be delivered through a set of storyboards with interface elements speculating on how different stakeholders could make use of them in their domains.

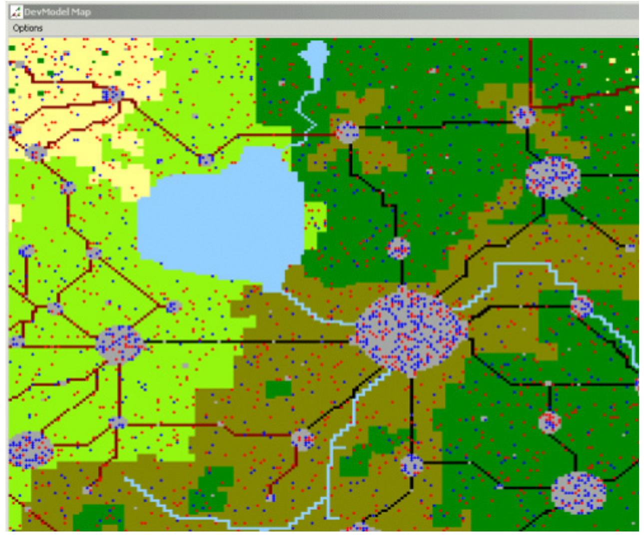
INTERSECTING CONTEXTS

Cities worldwide are increasingly digitalizing transport, buildings, energy, and communications, and so as urban environments. In recent years, urban forests received much attention as ‘crucial infrastructure providing tangible benefits and values that enhance quality of life, safety, and public health’ (FAO, 2016). Featuring forests as solutions for contemporary urban challenges such as climate change, urban heating, air quality, and disconnection with nature (Phillips & Atchison, 2018), smart cities now program green as well as gray infrastructure (Gabrys, 2022).

Termed as smart urban forest, this particular mode of governance utilizes digital technologies to support, enhance, and influence urban forest policies (Prebble et al., 2021). Numerous digital technologies and infrastructures are now monitoring, networking, managing, and remaking forests as they attempt to observe environmental change, optimize forests for resource management, and intervene in sites of forest loss (Gabrys et al., 2022). With diverse sensing, data analytics, and automation technologies, forests are now represented as a set of data. Global cities such as New York, London, San Francisco, Amsterdam, and Melbourne have already undertaken these digital transformations, archiving their forests online as an open data set: for example, a survey of the existing urban treescape, calculations of canopy cover, or valuations of existing green space. Some go even further to make the data more accessible for the city and its residents by providing digital maps visualizing each public tree’s location, genus, and its useful life expectancy (Philips & Atchison, 2018).

WHAT IS AN AGENT-BASED MODELING?

In simple terms, agent-based modeling (ABM) refers to a way of simulating the complex system by modeling actions and interactions of autonomous agents. Here, an agent is an abstraction for an autonomous, reactive, and proactive information-processing entity. Individual agents are typically characterized as boundedly rational, acting on their internal decision-making rules. Through these determined simple behaviors and interactions, system behaviors that are not explicitly programmed emerge. A typical agent-based model has three elements:



Parris, B. (2018). Untitled [Image]. Integrated Development. https://www.brettparris.com/abm/

- A set of agents, their attributes, and behaviors.
- A set of agent relationships and methods of interaction: an underlying topology of connectedness defines how and with whom agents interact.
- The agents’ environment: Agents interact with their environment in addition to other agents.

A step in ABM refers to a unit of time where agents in the simulation interact with each other and their environment based on the given data and the behavior rules. In each step, the following sequence of events occurs:

1. *Agent Actions*: Each agent in the model makes decisions based on its programmed behavior rules, and performs actions accordingly. These actions include

movement, interaction with other agents, and changes to their attributes or states.
2. *Interaction*: Agents interact with other agents and their environment. These interactions involve sharing information, exchanging resources, competing for resources, or collaborating on tasks.
3. *Environment Update*: The environment or the state of the system may change based on the actions of the agents. This includes changes in resource availability, environmental conditions, or other external factors.
4. *Data Collection*: Data on agent behaviors, interactions, and the state of the system are collected at each step for analysis and visualization.

The simulation progresses by repeating these steps over a designated timespan.

One of the key technologies that promote forests' transition into infrastructures is digital twin simulation. Utilizing a digital replica of the forest, diverse granular computational experiments can be conducted under different management schemes. In many smart cities, these simulation data facilitate more efficient and effective management of forest ecosystems by informing city governments or urban planners on deciding which trees to plant and where (Pinho et al., 2018). For example, in cases where the benefits of an urban forest far exceed its costs, it provides a compelling argument for maintaining the forest. In this way, more investment can be made into the forest to generate more carbon, water, health, energy, economic, and social benefits.

Developed by Lucidminds, Green Urban Scenarios (GUS) is a digital twin representation and simulation of urban forests and their impact. This is powered by agent-based modeling (ABM) which simulates the forest's growth and translates that into expected ecosystem benefits under varying weather conditions, maintenance regimes, species compositions, and their exposure to diseases.

Through multiple iterations of these steps, researchers can observe how the collective behavior of individual agents leads to emergent patterns at the system level. The step-based approach allows for the exploration of various scenarios and the observation of how the system evolves over time under different conditions. For this reason, it is particularly important to examine which agents are embedded in the model and how they are programmed to behave or interact with others. Each of these efforts of measuring, mapping, and valorizing the dynamics of urban forests draws attention to how humans biasedly define the forests, especially focusing on what they would benefit from them. Hence, the performativity of these data and modeling endeavors should be heeded. It is clear that quantitative valuing and mapping enact epistemo-cultural order, demonstrating particular forms of nature and political agendas (Phillips & Atchison, 2018).

Unfortunately, across the diverse disciplines including science and technology studies (STS), environmental humanities, geography, urban design and planning, and HCI, scholars have raised concerns about the lack of consideration for multispecies in cities and insisted on reconceptualizing the urban as a co-produced site by both humans and nonhumans (Sheikh et al., 2023; Fieuw et al., 2022; Quinn, 2020; Clarke et al., 2019; Houston et al., 2017; Smith et al., 2017). The traditional binaries between nature and culture are being challenged to embrace the entanglements between human and nonhuman worlds including "things, objects, other animals, living beings, organisms, physical forces, spiritual entities" in urban contexts (Clarke et al., 2019). Recognizing the agencies of nonhumans in shaping cities and places allows us to explore worlds that have been rendered invisible or inanimate under Western, Enlightenment, and Modernist thinking. Despite these vigorous discourses, however, there still remains a lack of empirical cases where the methods to design for and with nonhumans are deployed in the real-world context.

Together with Lucidminds, we see an opportunity to listen to and speak with forests by incorporating multispecies agents and their interactions into the digital twin of the forest.

Taking digital twin simulation as a performative[1] and material-discursive[2] apparatus to make alternative worlds and futures, we aim to imagine more-than-human governance where urban forests are more-than-infrastructures.

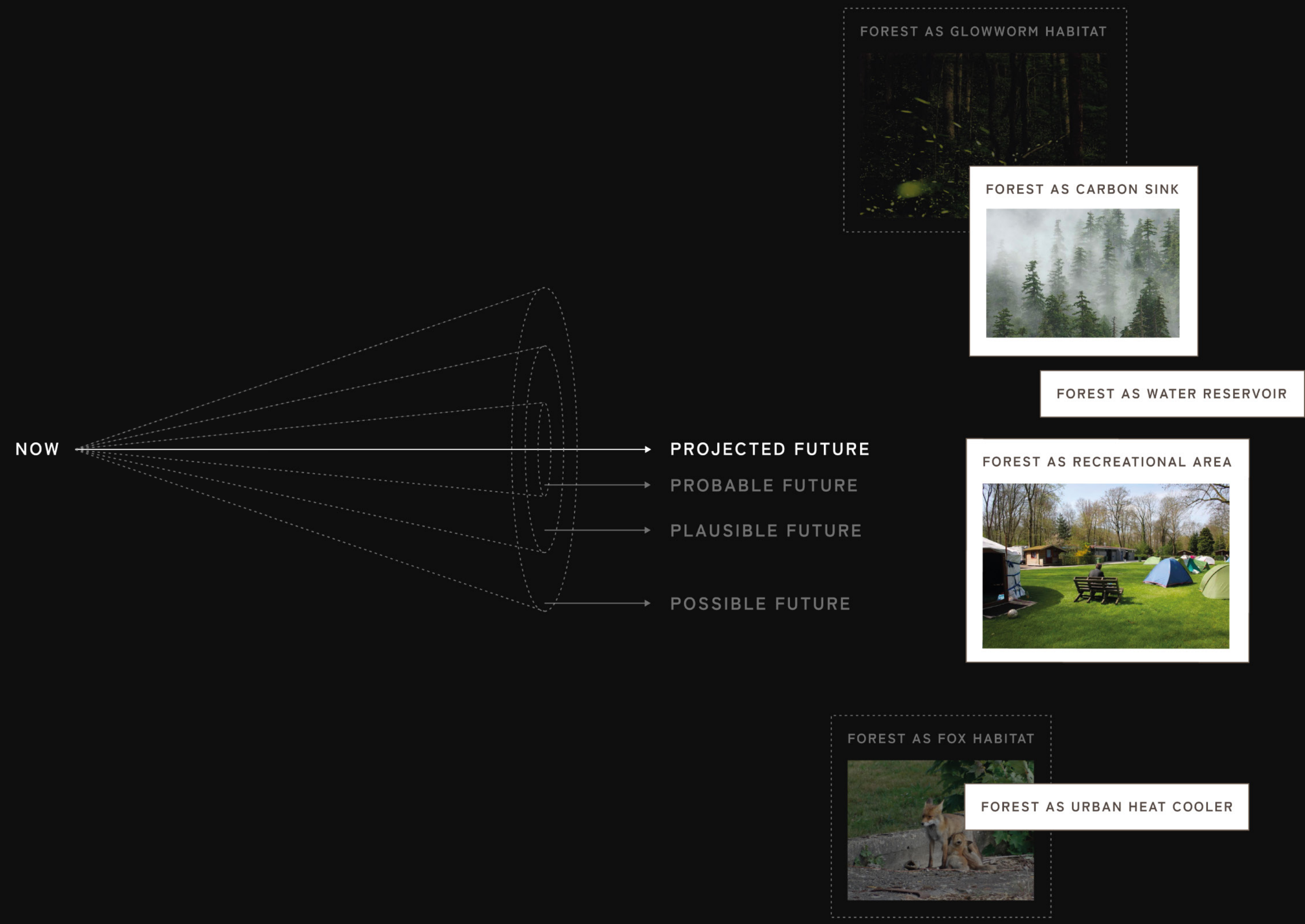
1 Simulation technology is performative in that production of future scenarios informs decision makings in forest management and becomes reality by being taken as actions.

2 Simulation technology is material-discursive in that it produces determinate meanings and material beings while simultaneously excluding the production of others.

SMART URBAN FORESTS

In smart urban forests, seemingly neutral data favor particular forms of nature and mobilize certain political agendas. While these data-informed decisions are seen to be less vulnerable to politicization (Joppa, 2017), the use of digital technologies does not elide politics but rather informs and extends politics into new engagements (Gabrys, 2020). It should be further investigated on how these technologies enable and constrain particular modes of governance and engagement with forests. Without such research, the development of smart environments, including smart forests, risks perpetuating social-political inequalities and undemocratic governance, as observed in the case of smart cities (Shelton et al., 2015; Zook, 2017).

This chapter starts with secondary research to understand the anthropocentric biases in smart forests and the potential harm they may pose to nonhuman species. The papers in the areas of digital geography and sociology were reviewed. Subsequently, in order to seek space to embrace considerations for nonhuman species, I examined the ABM model from Lucidminds. The model specification and documentation were explored while referring to the previously discovered anthropocentric biases.



ANTHROPOCENTRISM IN SMART URBAN FORESTS

Smart urban forests tend to foreground efficiency in capturing and translating forest data due to computational costs. The liveliness of forest ecosystems and capabilities are diminished in the process of data collection, which primarily emphasizes height and canopy cover while neglecting other crucial aspects. These overlooked dimensions include temporal differences, diverging boundaries (e.g. proximity to other trees and roots, water, fungi), the presence of family members or kin, and capabilities such as finding water, seasonal response, and plant learning (Prebble et al., 2021). We further elaborate on these four aspects that fall in the blind spot of human perspective.

MORE-THAN-HUMAN TIMESCALE

Clarke et al. (2019) discuss the digital design challenge arising from the constraints of finite linear human timescales. Notably, political and research funding periods are significantly shorter than the temporalities observed in the more-than-human realm, such as climate change or the age of tree biomes. This temporal difference frequently results in giving higher priority to interventions that can produce immediate and discernible outcomes within the short term. Pschetz and Bastian (2018) claim that these temporal inequalities, that the times of some are more invested in than others, should be tackled by promoting temporal empathy. Mckibben (2008) also stresses the need to broaden our understanding of time to reflect social and political spheres, and our place within more-than-human worlds, thus acknowledging multiple rhythms.

DIVERGING BOUNDARIES

Cooke, Landau-Ward, and Rickards (2019) draw attention to the colonial spatiality that constrains urban greening policies and practices. Based on Western ideas of property rights, private property owners and experts are often bestowed disproportionate power in placemaking. These limitations prevent policies and practices from being attuned to or considering more-than-human lifeworlds, limiting trees' access to water, nutrients, soil microbes, fungi, and kin by property boundaries (Prebble et al., 2021). Philips and Atchison (2018) also share the story of Bunya pine (Araucaria bidwilii) in Australia where its large, heavy cones 'misbehaved' by being dropped into the grounds of Machattie Park, causing concern for people walking below and causing the Council to cordon off the area.

NONHUMAN ACTORS: FAMILY MEMBERS, KINS, AND OTHER SPECIES

The forest data often depicts tree clusters in isolation, disregarding the essential presence of other organisms such as plants, fungi, and pollinators that contribute to tree ecologies. Sensing technologies often either fail to capture these organisms or are not used for such purposes, rendering them invisible. Conventional observational technologies like 3D imaging, remote sensing, and aerial photography primarily focus on capturing a top view, neglecting the dynamics and interactions that occur underground (Prebble et al., 2021).

NONHUMAN AGENCY

The limited or absent data on the capabilities of nonhuman species impedes the exploration of potential collaboration with them. The vast amount of research has shown that nonhuman species are capable of a broader range of cognitive, emotional, and symbolic behaviors than they have traditionally been given credit for in Western cultures (Bastian et al., 2017). This body of work includes studies on mimosa plants' ability to discern between various threats or adapt their responses to save energy, and the learning capacities of pea plants to associate and react to different stimuli.

POTENTIAL HARM IN SMART URBAN FORESTS

Below further articulates types of potential harm that can be caused by the aforementioned anthropocentric biases.

DIGITAL HARM

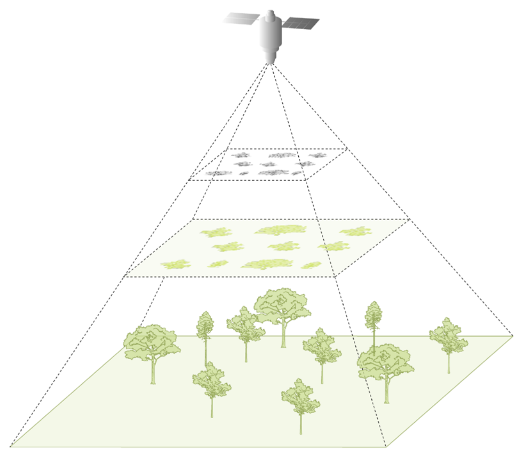
Digital harm (Lupton, 2019) refers to the negative effects that befall an entity when its data is exploited against its interests. A common example of this is the misuse of tree location data for acts of vandalism (Verma, 2016). Another potential digital harm, similarly to human data, arises when particular tree data metrics favor certain individuals over others (Lupton, 2019). Certain trees are subjected to be pruned or removed due to their digitalized data such as their species, position in relation to boundaries, expected or estimated 'useful life', ecosystem services, or monetary values. For instance, trees with higher monetary value, indicated by wider canopy measurements or longer remaining useful lifespans, receive greater protection and resource allocation.

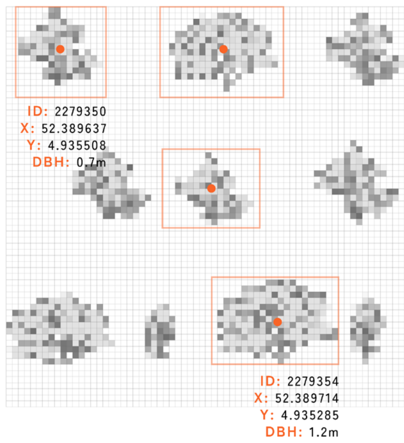
DATA SURVEILLANCE

The decisions regarding tree planting, including species selection and location, are typically made exclusively by human council workers. Prebble et al. (2021) and Lupton (2019) argue that this limited involvement of nonhuman entities in decision-making processes can be seen as a type of data-driven surveillance where, in this case, trees have no ownership or control of their data.

NEOLIBERAL VALORIZATION OF TREES

While the concept of Nature 2.0[3] allows the reimagination of nature online, Buscher (2016) cautions that the neoliberal capitalist paradigm as the basis of their design might promote and obfuscate the commodification of nature. Numerical data including coordinates of geographic locations, tree measurements, ecosystem services, and percentage of canopy area are often translated and evaluated in monetary terms, resulting in the promotion of the planting and protection of certain tree species over others based on the utility of these trees to humans. Digital technologies rooted in neoliberal capitalism may reinforce current power dynamics within existing structures so that social, cultural, political, and multispecies inequalities are recreated and solidified when designed and employed by planning institutions (Lupton, 2019; Luque-Ayala, 2018; Rose, 2017). The shift to market-led digital urban forest governance, therefore, requires extra attention as market-based values may not align with social, environmental, and more-than-human values (Konijnendijk van den Bosch, 2016).





3 Nature 2.0 refers to the engagement of humans and nature through web applications such as social media platforms (Buscher, 2016).

EXAMINING THE GREEN URBAN SCENARIOS (GUS)

Computational models inevitably leave certain parts of reality hidden, unseen, or filtered as they prioritize specific agents and features for representation. These selection processes should be carefully noted in that they implicitly steer users to attend to what is embedded within the model. Currently, there exists a limited consideration of more-than-human aspects beyond the focus on trees when designing models for smart forests (Prebble et al., 2021). In order to identify opportunities for accommodating multispecies realities in GUS, I examined its model specification[4] and documentation[5] based on the three criteria (i.e. temporality, spatiality, actor/agency). Below articulates how GUS describes the temporality, spatiality, actors, and agencies of the forest. It should be noted that the following analysis is based on the demo version of GUS, meaning that the more granular expressions of time, space, and agency are possible.

OVERALL STRUCTURE

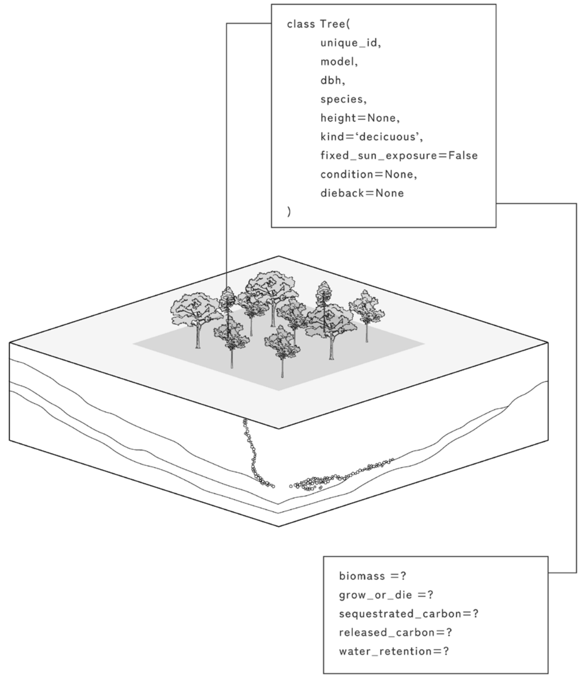
GUS models urban ecosystems in a specific location and simulates the ecosystem growth and development over time using weather data. The digital ecosystem is composed of mutually interacting agents including trees, people, diseases, and invasive species. The model dynamics thus emerge from the agents' interactions given the weather conditions over time.

TEMPORALITY

In the demo version of GUS, the simulation runs on a yearly basis. This means that each simulation consists of iterations (steps) where a single step happens over a year in

4 https://github.com/lucidmindsai/gus/tree/main/docs

5 https://lucidmindsai.github.io/gus/



CLASS: TREE

Variables:
- carbon_storage_cap
- sequestration_at_maturity
- carbon_coeff
- decomposition_coeff
- sun_exposure_rates
- condition_multiplier
- root_to_shoot_ratio
- crown_to_trunk_ratio

Methods:
- advance()
- check_dieback()
- compute_biomass()
- compute_contagion_risk()
- compute_decomposition()
- compute_light_exposure()
- compute_sequestration()
- estimate_tree_height()
- fleming_height()
- grow()
- replace()
- step()
- update_crown_height()
- update_crown_width()
- update_tree_height()

CLASS: URBAN

Variables:
- dt_resolution #in meters
- site_types = ['park', 'street', 'forest', 'pocket']

Methods:
- agg_std_sequestration()
- aggregate()
- aggregate_sequestration()
- compute_carbon_release_rate()
- compute_current_carbon_release()
- count()
- get_weather_projection()
- next_id()
- reset_randomizer()
- run_model()
- step()

CLASS: WEATHERSIM

Variables:
- ffdays_mean
- ffdays_var

Methods:
- check_frost_free_days()

CLASS: CARBON

Variables:
- coeff
- storage_cap

Methods:
- compute_biomass()
- compute_carbon_storage()

CLASS: CALIBRATION

Variables:
- avg_shade_factor
- kappa
- leaf_storage
- leaf_transition_days
- m_to_mm
- maximum_impervious_cover_storage
- maximum_pervious_cover_storage

Methods:
- set_surface_storage_rates()

Tree biology
Tree's agency
Environment
Human intervention

computational time. Within each step, each agent performs tasks imitating what a real agent (e.g. a tree) would do during a year. For example, within a year, trees would be exposed to the weather conditions, compete with other trees for sun exposure, be exposed to various diseases, or be replaced by humans' site maintaining actions, which in turn influence the forest's growth. In each step, the growth function of the class Tree updates the DBH of the tree. Likewise, this yearly based progression of time tends to interrelate with the temporality in GUS. For instance, the WeatherSim agent describes the forest's time into frost and frost-free days within a year, and the function pai_seasons calculates the Plant Area Index (PAI) with respect to leaf on and off seasons. These time indicators facilitate the calculation of the forest's ecosystem services. The frost and frost-free days correlate with a tree's carbon sequestration capacity in that the frost-free days are seen as a period where a tree can sequester carbon. Also, leaf on and off seasons are related to a tree's water retention capacity in that leaves use the saved water during photosynthesis or through evaporation.

SPATIALITY

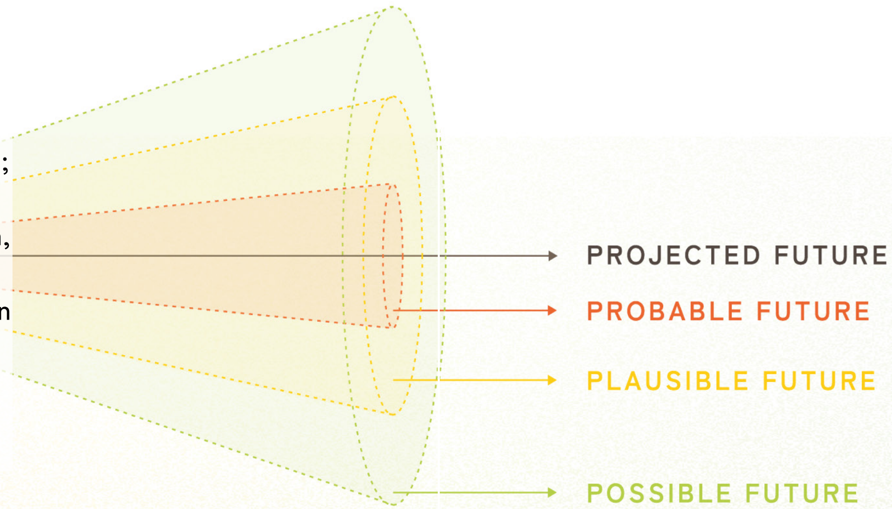
The spatiality of the forest is expressed as a digital grid where each tree is allocated its own x and y coordinate. Therefore, each tree has a unique place in the digital site and is surrounded by neighboring trees and other agents. This specific location relates to other site characteristics from the database such as soil type, site size, the distance among trees, and sun exposure. Similar to the temporal factors, variables that describe the spatiality of a tree correlate with its carbon sequestration and water retention capabilities. For example, sun exposure, which evaporates water, is expressed with shade factor and Crown Light Exposure (CLE). Shade_factor refers to the percentage of sky covered by foliage and branches within the perimeter of individual tree crowns. Moreover, trees check the state of their neighboring trees and thereby compute their current CLE.

ACTOR/AGENCY

Above all, the class Tree is represented as a set of variables such as ID, diameter at breast height (DBH), species, height, and condition. In tandem with the purpose of GUS to estimate and calculate the forest's ecosystem benefits, such attributes are correlated with quantifying each tree's ability to sequester carbon and retain water. For example, DBH, species, and height are used to calculate the biomass of a tree which can be translated into the estimated amount of sequestered carbon. Furthermore, the growth of the tree is described as an increase of DBH on frost-free days. The value of DBH is later translated into biomass, which also facilitates the calculation of the forest's ecosystem services. In addition, trees in the forest are described as a discrete entity, lacking the interactions between the trees or those between trees and other species inhabiting the forest.

DECENTERING AS METHODOLOGICAL EXPERIMENTATION

As the preceding chapter demonstrates, urban forests are often tied to and valued for the ecosystem services they provide. However, when trees stray from human standards of what is acceptable and desirable, they become targets of removal. While these ecosystem benefits or potential risk factors serve as primary indicators in deciding whether the trees belong to a certain location or not, neither such value nor risk is inherent to trees. Rather, whether those trees belong is a relational question; a question that requires consideration of relations which trees form as they grow in certain places over time (Phillips & Atchison, 2018). Then the challenge is no longer a simple question of 'What species should we plant and where?' but 'How can the negotiation with trees and others be made beyond the temporal, spatial, and agential disjuncts between human nonhumans?' This chapter shows the journey of exploring ways to attend to these plural subjectivities.



DECENTERING IN HCI

In recent years, the fields of design and HCI have encountered a more-than-human turn where design researchers and practitioners are increasingly engaging in designing for and with nonhumans, such as things, animals, and robots. This shift has been propelled by two main drivers, which urged humans to be ever more entangled with nonhumans. One is the pressing environmental crisis, which imprints the fact that humans and other species share the same fate by residing on Earth together. The other factor stems from emerging technologies being highly embedded in our everyday lives with new sensing and processing capabilities (Coskun et al., 2022). These called for researchers to critically reflect on how their own perspectives, biases, and positions of privilege influence knowledge production and interpretation.

Under these circumstances, decentering has been a key strategy in more-than-human design (MTHD) and posthumanist HCI to encounter more-than-human entanglements, attune to nonhuman perspectives, and open up to more porous boundaries with nonhuman agencies (Nicenboim et al., 2023). Several of these endeavors have been developed into methods, including thing ethnography (Giaccardi et al., 2016), interview with things (Chang et al., 2017), techno-mimesis (Dörrenbächer et al., 2020), object personas (Cila et al., 2015), metaphor (Byrne, 2022), provocative prototyping, speculative enactment, and noticing (Biggs et al., 2021).

Yet, there remains a need for methodological experiments and advancements in MTHD, particularly in contexts where humans grapple with a lack of control or more-than-human concerns take precedence over human-centric agendas (Nicenboim et al., 2023; Giaccardi & Redström, 2022), such as forests.

DECENTERING IN THIS PROJECT

This project focuses on the fact that forests are represented as a set of data collected and interpreted by humans. To empower forests in governing their own dynamics, it becomes essential to decenter the process of data collection and sensemaking from anthropocentric approaches. This entails challenging our understanding of what a forest is and the way we learn and know a forest. Noting that the decision-making around whether a certain tree belongs to the forest or not is inextricably relational, I embarked on experiments to find the methodology for capturing interrelations within forests.

EXPERIMENT #1: THING ETHNOGRAPHY

In order to capture entanglements within the urban forest beyond anthropocentric assumptions, thing ethnography was chosen as the initial research methodology.

WHAT IS THING ETHNOGRAPHY

Thing ethnography (Giaccardi et al., 2016) is a methodology to seek new ways of collaborating between humans and nonhumans (referred to as ‘thing’) by interpreting data collected from the perspective of the thing. In this framework, a thing is not regarded as a passive object but rather an active participant in social practices and relationships. The viewpoint of a thing, situated within dynamic relations with other entities, offers a distinct perspective that differs from human perspectives. Equipped with software and sensors, these things can offer insights into fields and perspectives that would otherwise be inaccessible to human ethnographers. These accounts emerge at the intersection of the data and trajectories made available by things and the theoretically informed analysis conducted by human researchers.

WHY THING ETHNOGRAPHY

Thing ethnography was selected as the initial exploration method to capture entanglements in urban forests for two primary reasons. First, data gathered from a thing's perspective encourages people to heed what might typically elude human senses. Secondly, it leverages limitations of human interpretation as opportunities to seek what we can feel but also exceeds our dimensions of time and scale. This pursuit of more-than-humanness differentiates knowledge produced through thing ethnography from that found in the fields of ecology and biology. By intentionally blurring the lines between the observed and the observer, thing ethnography generates data worlds which bridge different worlds of humans and nonhumans. This kind of knowledge is especially valuable for taking a more-than-human approach to the design process.

CHALLENGE AND OPPORTUNITIES

Applying thing ethnography in the context of urban forests posed several challenges. Above all, the research context was different from its typical use cases. Thing ethnography has been employed to comprehend social practices anew by observing entanglements around designed objects. The unique use experience that the object affords (which can be seen as the object's agency) plays a pivotal role in such practices, which opens up possibilities for reshaping the social practices through co-performance between the object(s) and the user(s).

On the other hand, the primary interest of this project wasn't to unravel the social practices of humans in urban forests, such as walking, cycling, or camping. Instead, the focus was on unearthing more-than-human encounters and entanglements that we, as human researchers, cannot preconceive. This posed difficulty in selecting specific contexts and methods for data collection since there was no predefined beacon to orient ourselves.

In addition, nonhuman species were inherently different from the concept of a 'thing' in thing ethnography. While both a 'thing' and nonhuman species are in relation to other entities and their environments, fulfilling roles by exerting their own agencies, there exists a fundamental difference. Deconstructing the inner mechanisms and algorithms of a 'thing' is relatively easy or at least doable as it is designed by humans. In contrast, accessing the inner workings of nonhuman species proves challenging, often verging on the impossible. This situation resembles the challenge of comprehending machine learning: while one can grasp the neural network's structure and its role in machine learning, understanding the exact logic governing its agency remains phenomenological. Similarly, one can grasp the functions of certain proteins or organs, yet the precise reasoning behind specific behaviors remains elusive. The only thing that human researchers can do is to try to attune themselves to these entities and speculate about their worlds.

PILOT STUDIES AND REFLECTIONS

While being aware of these two challenges, I conducted iterative pilot studies as a form of “learning by doing”. For a month, I took four iterative cycles of observing, selecting the site, installing a camera trap, checking the footage, and reflecting. While the camera footage itself didn’t provide significant insights, this iterative process of scouting locations for camera trap installation and reflecting on more effective methods to capture entanglements helped uncover what remained previously unnoticed within the forest.

For example, as GPS did not work properly in the forest, I had to remember the site where I installed the camera by actively searching for characteristics of the site and the way to get there. Furthermore, during the retrieval of the camera trap after a week of rainy days, I spotted tiny insects using the back of the camera as a shelter. This made me rethink the conventional ways of knowing through a camera. A camera is designed to capture a visual scene, but, at the same time, it possesses a corporeal body that enables physical interactions. This experience led to a further question on what corporeality means in a digital twin of reality: How can the bodies of multispecies agents open up new ways of knowing digital forests?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20 °C 68 °F 2023/04/23 11:17:31 0054
14 °C 57 °F 2023/04/18 17:13:39 0099
3 °C 37 °F 2023/04/20 01:15:12 0073

EXPERIMENT #2: MORE-THAN-HUMAN FOREST BODIES WORKSHOP

In order to account for plural perspectives while overcoming the human time and space scales, the notion of body (Homewood et al., 2021) was taken as a conceptual lens to collect and make sense of forest data across diverse temporal, spatial, and agential dimensions. Existing bodies of different nonhuman species were employed to attune to respective perspectives and envision how each species would experience or engage with the forest. Additionally, imaginary bodies of the forest were crafted to capture the events that emerge from these entanglements.

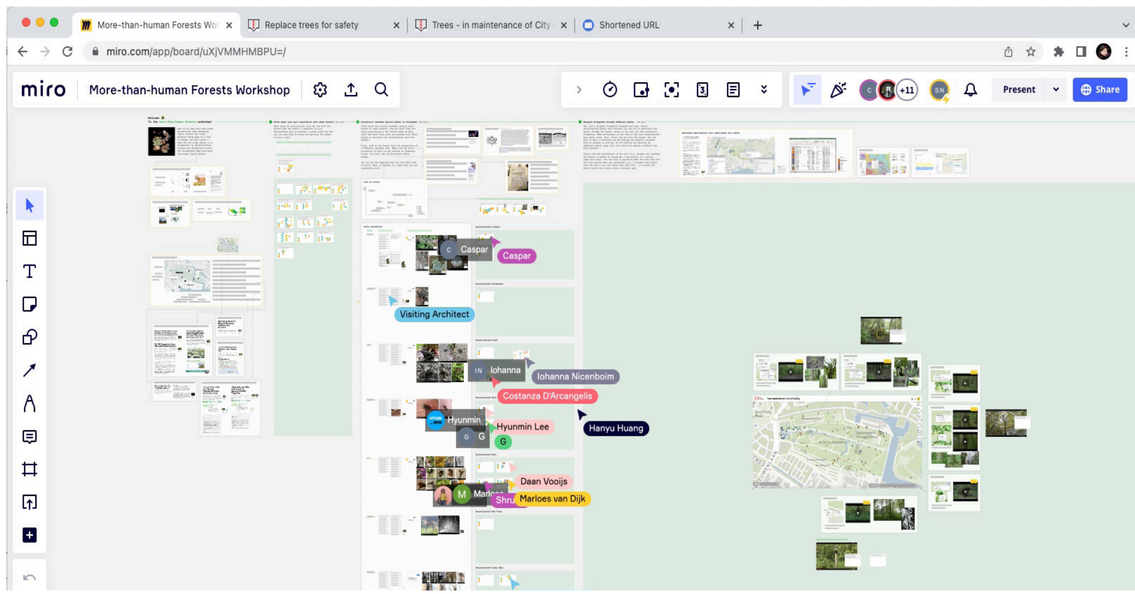
BODY IN HCI

The concept of the body has gained significant importance in the field of human-computer interaction (HCI), serving as both a site for design and a design tool. On one hand, the body as a site for design has become more prominent due to the proliferation of technologies directly situated on or inside the body. On the other hand, the body as a tool for design has been recognized through design practices that address and enhance the situated knowledge of the designer's own body, as a way to obtain knowledge upon which design decisions can be made. The body is inherently complex. We have bodies, we are bodies, and we exist in continuous relations with other bodies. The body is both a material object and the origin of our subjectivity. It seems stable, but in fact, it is in a constant state of becoming. As a result, this complexity has led HCI to draw from a range of disciplines, rationales, methods, and ontologies, revealing that the term "body" can hold different meanings for different groups in different contexts. Homewood et al. (2021) trace the evolving conceptions of the body across the progressions from 1st to 4th wave HCI through the narrative arc of the user to body, body to bodies, and bodies to more-than-human bodies. This has been achieved by first emphasizing the corporeal situatedness of the "user," then transforming the ubiquitous solitary "body" into the plural forms of "bodies," and finally complexifying the composition of "bodies" so that they either already comprise more-than-human elements or invite further reconfiguration.

In the workshop, we adapted this progression of the body in conceiving more-than-human bodies of Vliegenbos: first using our own human bodies to sense and understand the forest, then attuning to diverse bodies of flora and fauna within the urban forest to expand the notions of and relationships with the forest, and finally creating a more-than-human body for the forest. These more-than-human forest bodies were later used to explore alternative ways to define and measure the healthiness of the forest.

SETUP

As the workshop necessitated a prior understanding of posthuman discourses (e.g. attunement, entanglement), the workshop was conducted with 12 design master students who were taking the course on more-than-human design. The workshop activities took place in the Miro board, except the final activity of drawing more-than-human bodies of the urban forest.



OVERALL PROCESS

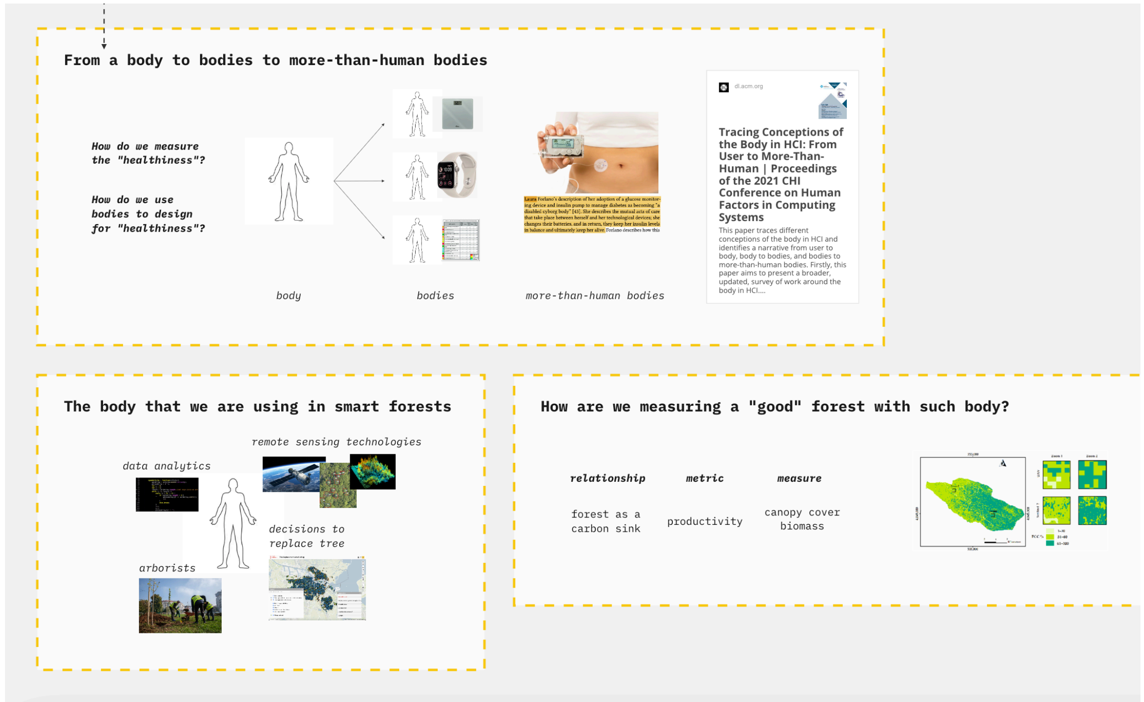
The workshop was structured around four activities, (1) sensitizing, (2) attuning, (3) situating and (4) recomposing, and concluded with a reflection session. Before delving into the activities, participants were provided with a brief introduction to the notions of the body in the context of healthcare and smart forests.

1. Sensitizing: Reflect on personal experiences and relationships with urban forests and how one used its own human body to sense and perceive the forest in such a way
2. Attuning: Deconstruct nonhuman species bodies in Vliegenbos by attuning to each species's body and relationship with the forest
3. Situating: Navigate Vliegenbos data through the deconstructed bodies by annotating what each species would have thought or done using its body
4. Recomposing: Make a more-than-human body of Vliegenbos by recomposing the deconstructed bodies

INTRODUCTION

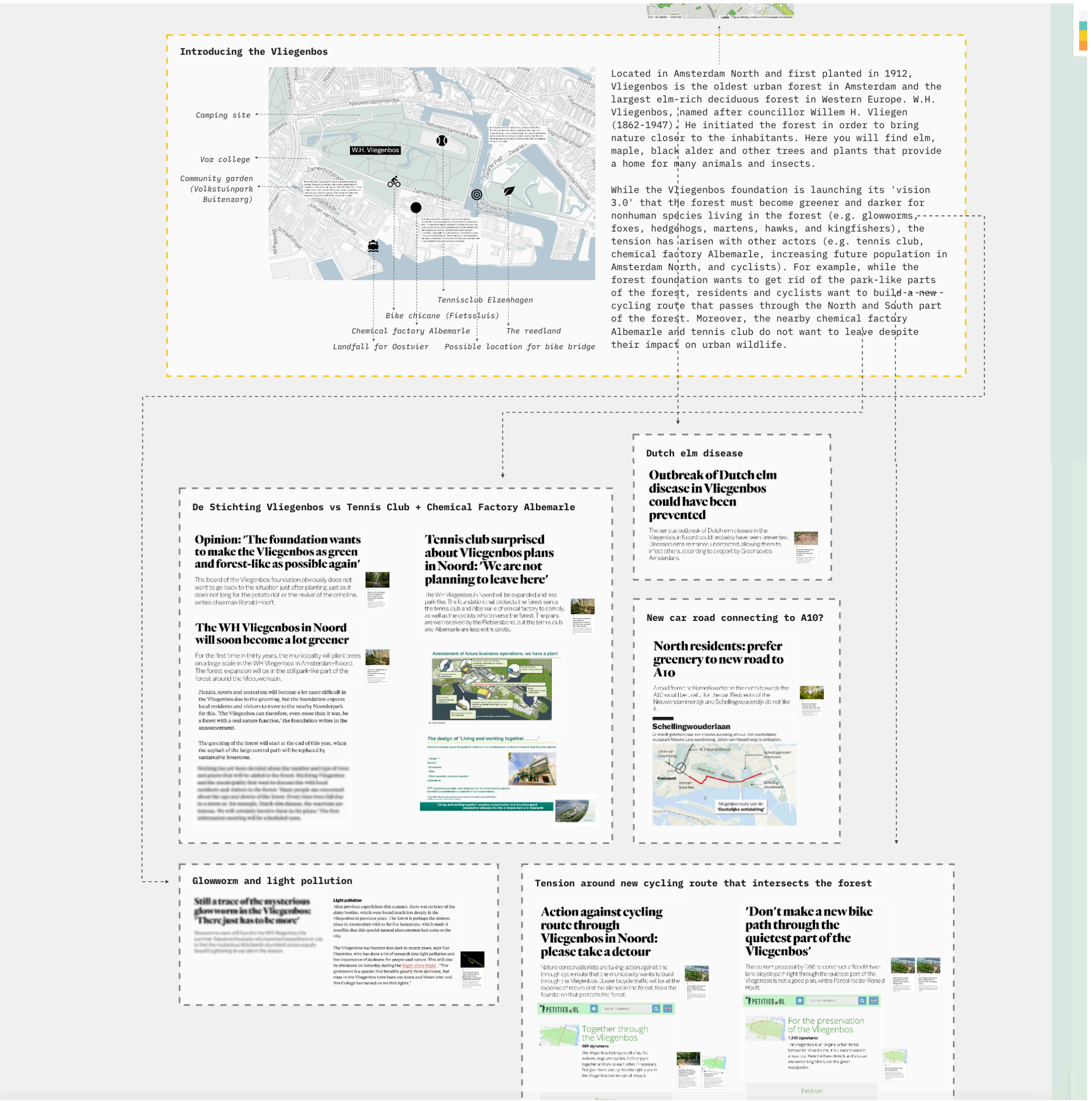
The workshop started with an introduction to the notions of the body in the context of healthcare and smart forest. First, brief explanations of different notions of the body in HCI were given, together with examples of how such bodies were differently used to measure the "healthiness" of human bodies. As the single standard notion of the body was multiplied to bodies along with the proliferation of data-collection practices, the body started to be understood as a range of idiosyncratic objects, each with its own outputs and signals. For example, a scale creates a numeric range of what "healthy" body weight is, and likewise, a health watch and a mental health survey generate their own interpretations of what "healthiness" is. This shift from body-to-bodies is well represented by Quantified Self movement with self-tracking technologies. In recent years, as technologies and humans became even more entangled, the conception of the body again moved from the bodies to more-than-human bodies.

Laura Forlano's (2017) perspective on glucose monitoring devices and insulin pumps as integral components of her body, collectively maintaining her well-being, illustrates this notion. The mutual acts of care between herself and the devices (e.g. she changes their batteries, and in return, they keep her insulin levels in balance) ultimately keep her (and her body) alive.



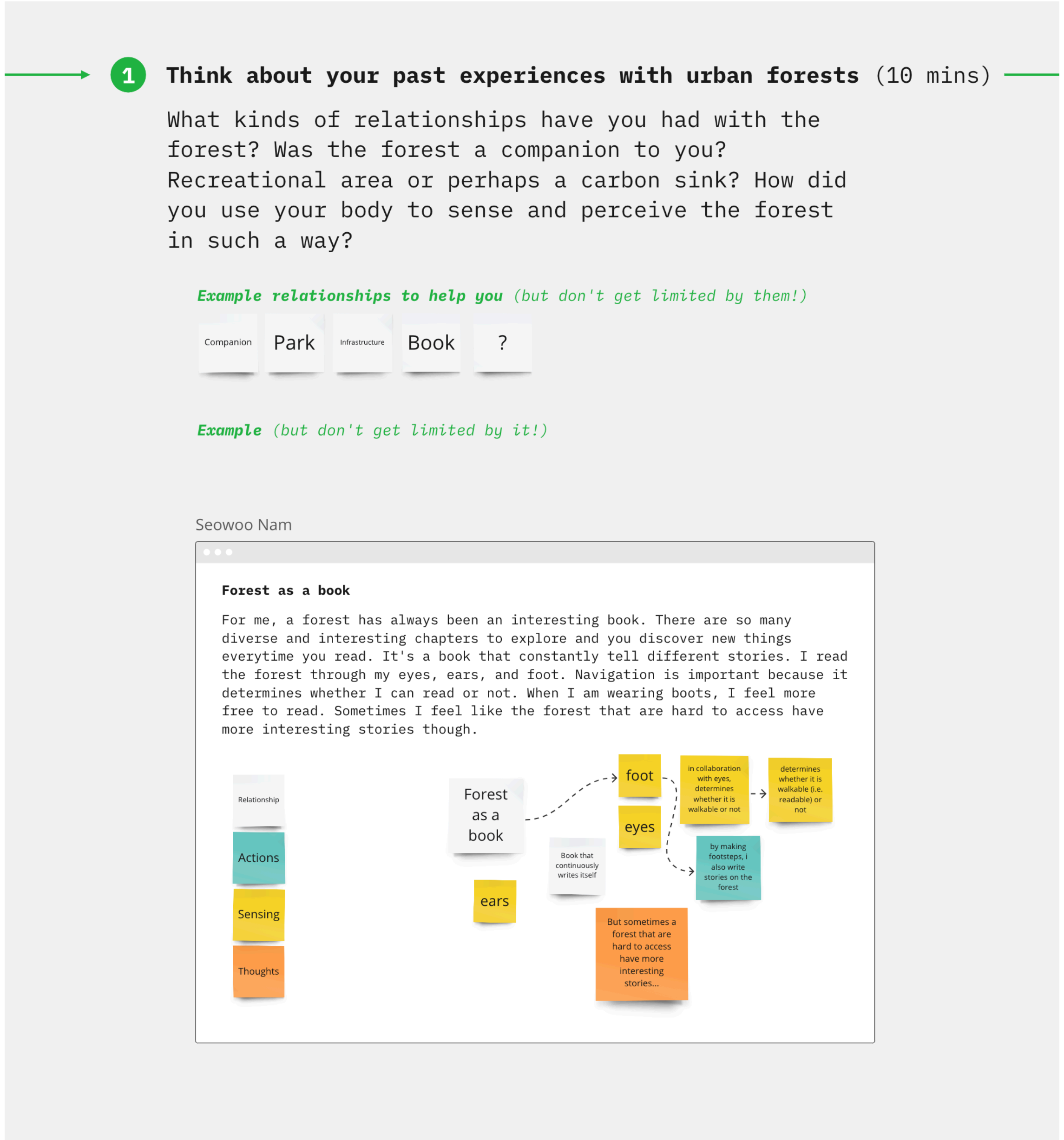
Next, the body that we are using to sense and perform smart forests was introduced, elaborating on how we are expanding our sensing capabilities with remote sensing technologies and how those collected data are operationalized through data analytics by informing decisions on which trees to plant, replant, or remove and where. Furthermore, an example was given on how such body is utilized to measure how "good" a forest is, thereby reinforcing certain relationships between humans and urban forests and solidifying certain futures: how futures of urban forest as a carbon sink are consolidated by measuring canopy cover and biomass to infer how productive and thus how "good" the forest is.

Finally, the project site, W.H. Vliegenbos, was introduced, highlighting its diverse human and nonhuman stakeholders and the tensions among them. Located in the Northern region of Amsterdam, Vliegenbos stands as the city's oldest urban forest, possibly the largest deciduous forest rich in elm trees across Western Europe. While the forest foundation and citizens who want to preserve the wildlife aspire to make the forest as greener, quieter, and darker as possible, cyclists, the tennis park, and the chemical factory all have different opinions on what they like the forest to be.



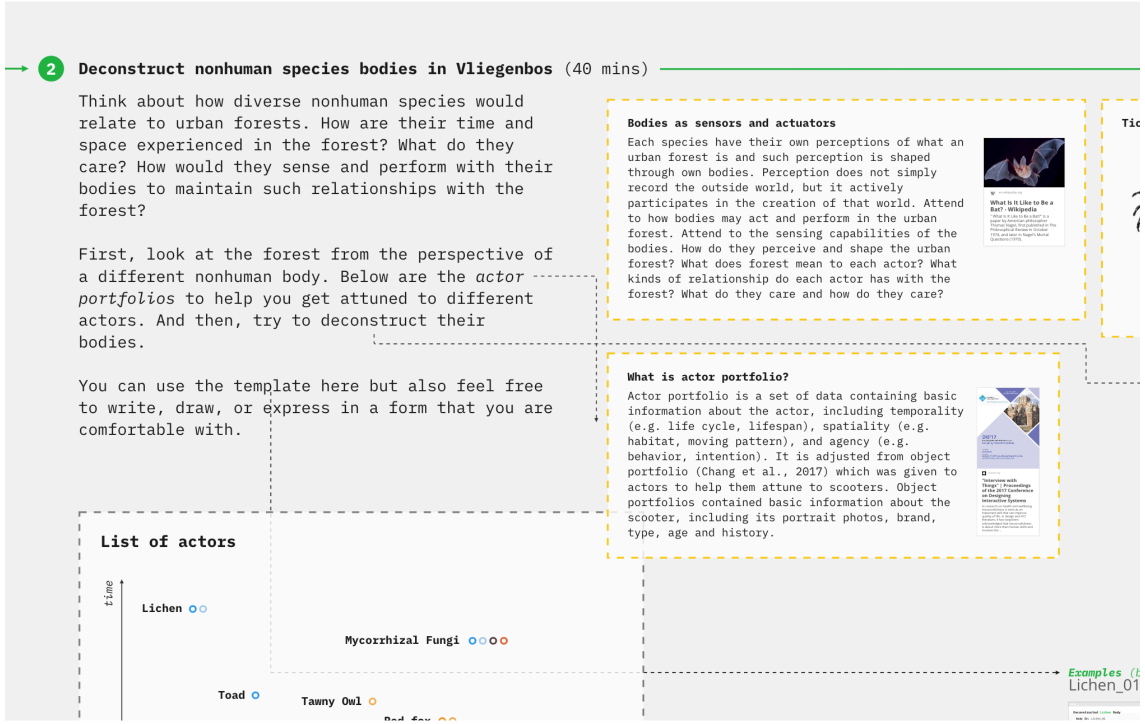
SENSITIZING

During the sensitizing activity, participants were asked to recollect their past experiences with urban forests. They were encouraged to reflect on what kinds of relationships they have had with the forest and how they used their own bodies to sense and perceive the forest in such a way. An example was given to help the participants get familiar with the template.



ATTUNING

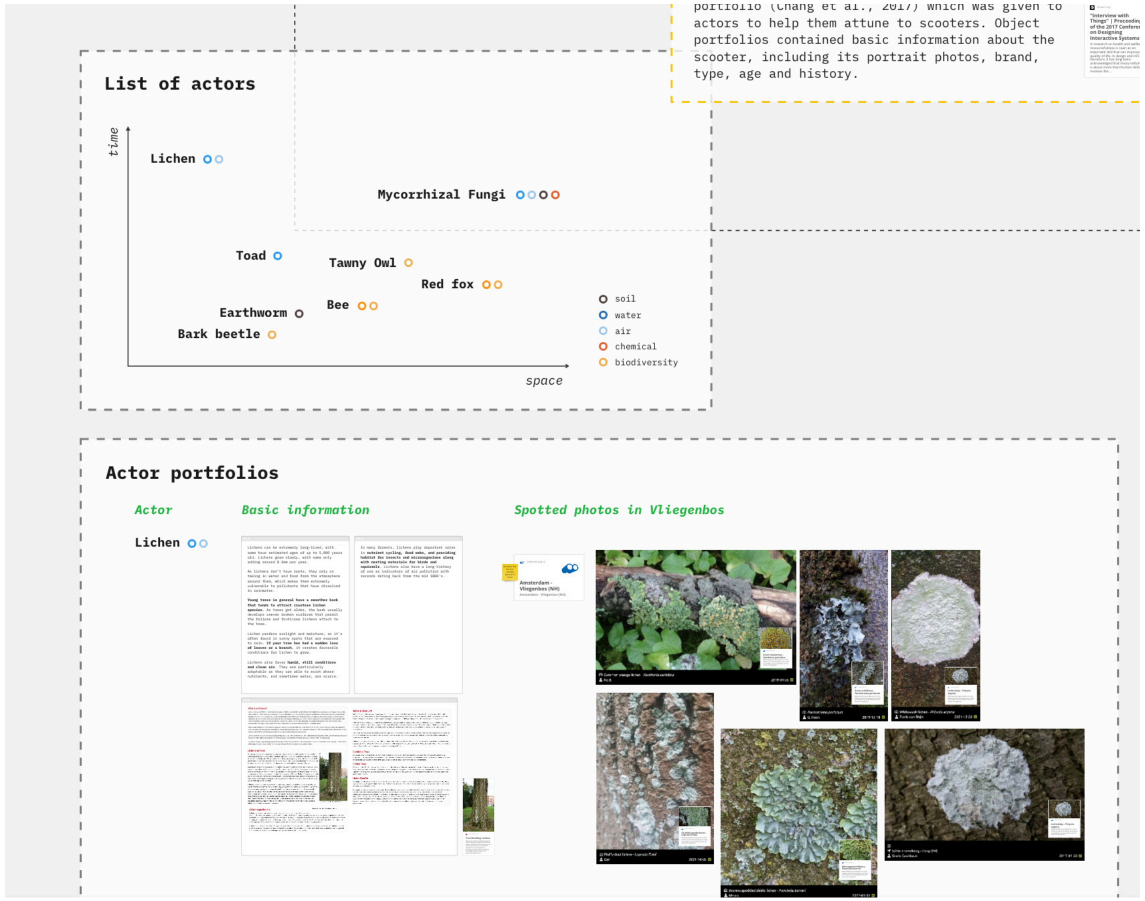
For the attuning activity, examples of how the bodies of a tick and a bee create their own perceived worlds were given as examples to help the participants understand bodies as roots of subjectivities, the production sites of personal and lived experience of the world.



Eight different nonhuman species were chosen as actors for the participants to attune to, considering their significance to the forest ecosystem and ecological concerns. For example, bumble bees are regarded as keystone species in most terrestrial ecosystems, as they are crucial for the reproduction of countless wildflowers thereby creating the seeds and fruits that feed wildlife including birds and bears.

Furthermore, toads are seen as a good bioindicator for water quality as pollutants in the water can cause detrimental health issues when absorbed through their skin.

To help the participants attune to these nonhuman species, actor portfolios (adapted from object portfolio by Chang et al., 2017) were provided. These portfolios contained basic information about each species, including temporality (e.g. life cycle, lifespan), spatiality (e.g. habitat, moving patterns), and agency (e.g. behavior, intention). In addition, photographs of the nonhuman species observed in Vliegenbos were provided to help participants immerse themselves in the context of the site. The images were sourced from the Dutch nature observation platform (https://waarneming.nl/).



(40 mins)

Bodies as sensors and actuators

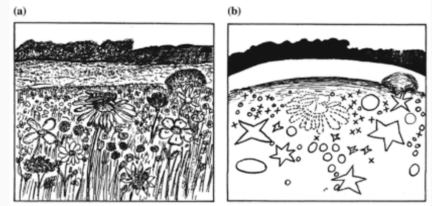
Each species have their own perceptions of what an urban forest is and such perception is shaped through own bodies. Perception does not simply record the outside world, but it actively participates in the creation of that world. Attend to how bodies may act and perform in the urban forest. Attend to the sensing capabilities of the bodies. How do they perceive and shape the urban forest? What does forest mean to each actor? What kinds of relationship do each actor has with the forest? What do they care and how do they care?

Tick's body

"...this eyeless animal finds the way to her watchpoint [at the top of a tall blade of grass] with the help of only its skin's general sensitivity to light. The approach of her prey becomes apparent to this blind and deaf bandit only through her sense of smell. The odor of butyric acid, which emanates from the sebaceous follicles of all mammals, works on the tick as a signal that causes her to abandon her post (on top of the blade of grass/bush) and fall blindly downward toward her prey. If she is fortunate enough to fall on something warm (which she perceives by means of an organ sensible to a precise temperature) then she has attained her prey, the warm-blooded animal, and thereafter needs only the help of her sense of touch to find the least hairy spot possible and embed herself up to her head in the cutaneous tissue of her prey. She can now slowly suck up a stream of warm blood."[7]

Thus, for the tick, the *umwelt* is reduced to only three (biosemiotic) carriers of significance: (1) the odor of butyric acid, which emanates from the sebaceous follicles of all mammals; (2) the temperature of 37°C (corresponding to the blood of all mammals); and (3) the hairy topography of mammals.

Bee's body

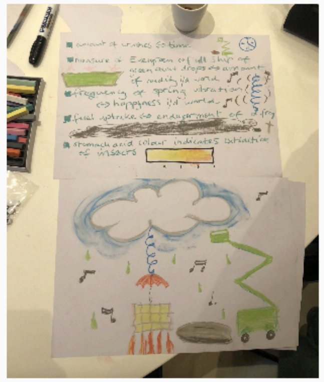


The Umwelt of a bee as illustrated in Von Uexküll (1934). a The environment of a bee how we perceive it as an external observer. b The same bee perceives only particular aspects of the same world, which constitute its Umwelt

What is actor portfolio?

Actor portfolio is a set of data containing basic information about the actor, including temporality (e.g. life cycle, lifespan), spatiality (e.g. habitat, moving pattern), and agency (e.g. behavior, intention). It is adjusted from object portfolio (Chang et al., 2017) which was given to actors to help them attune to scooters. Object portfolios contained basic information about the scooter, including its portrait photos, brand, type, age and history.

Deconstructing a frog



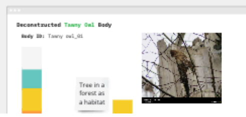
The picture on the left is a frog. The participant deconstructed a frog into singing (i.e. musical notes), jumping legs (i.e. scissor lift), and digestive system (i.e. yellow box). For example, she thought the frequency of spring vibration, which generates musical notes, mean happiness in the world (Croaking frogs have long been regarded as indicators of good rain and croaking is their way of finding mates).

Examples *(but don't get limited by it!)*

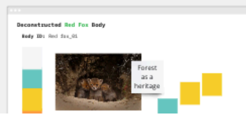
Lichen_01

Earthworm_01

Tawny owl_01

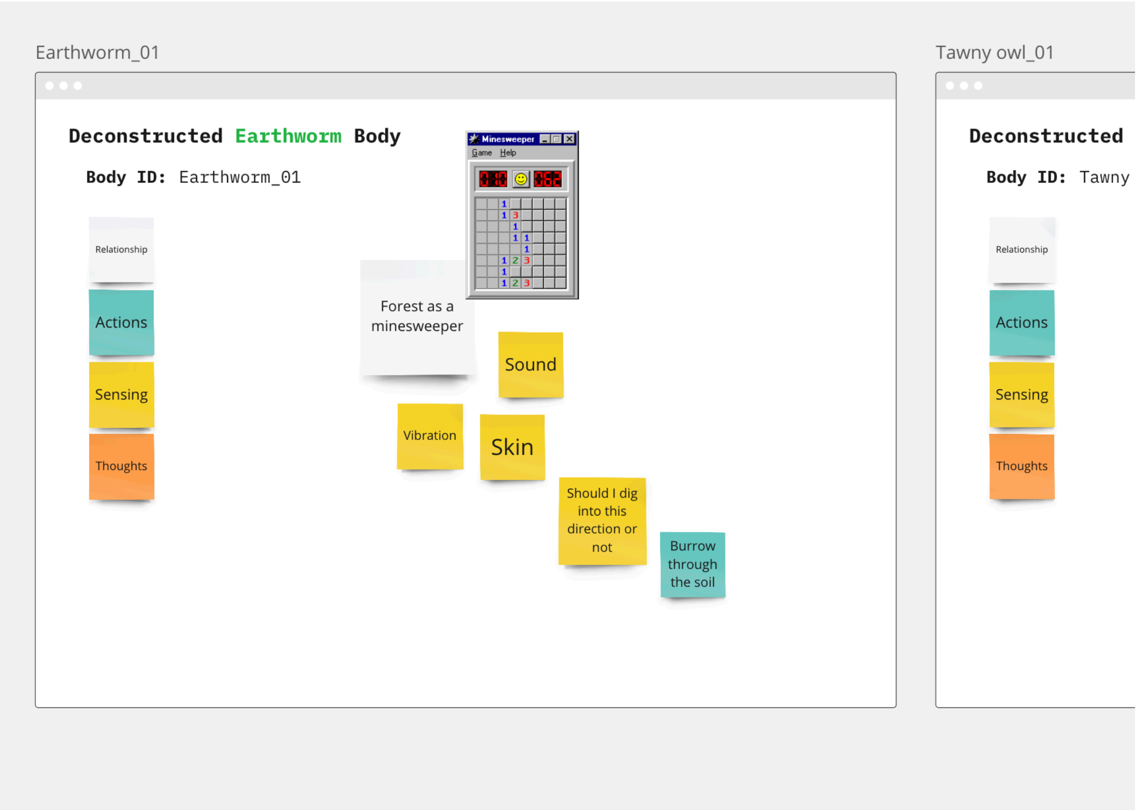


Red fox_01



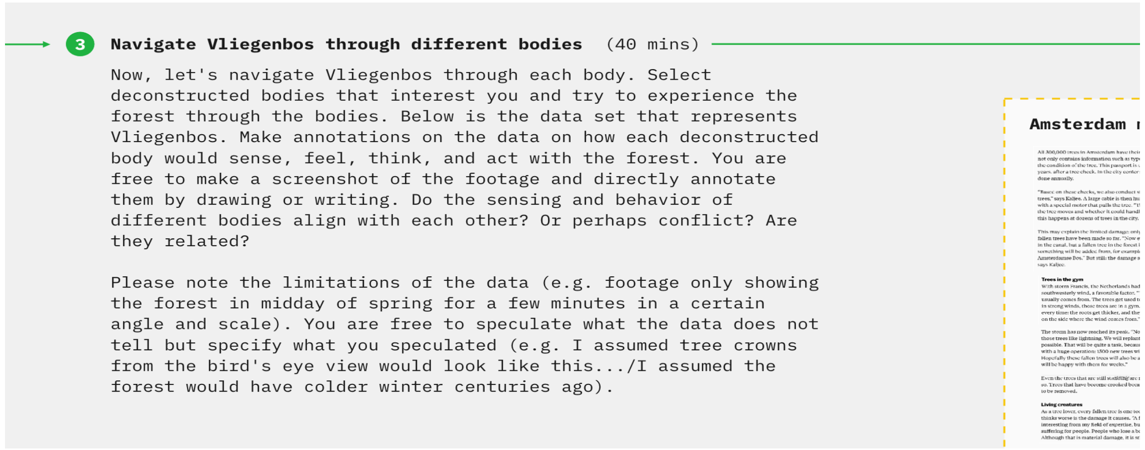
soil
water

Lastly, the examples were given to help the participants get familiar with the template.

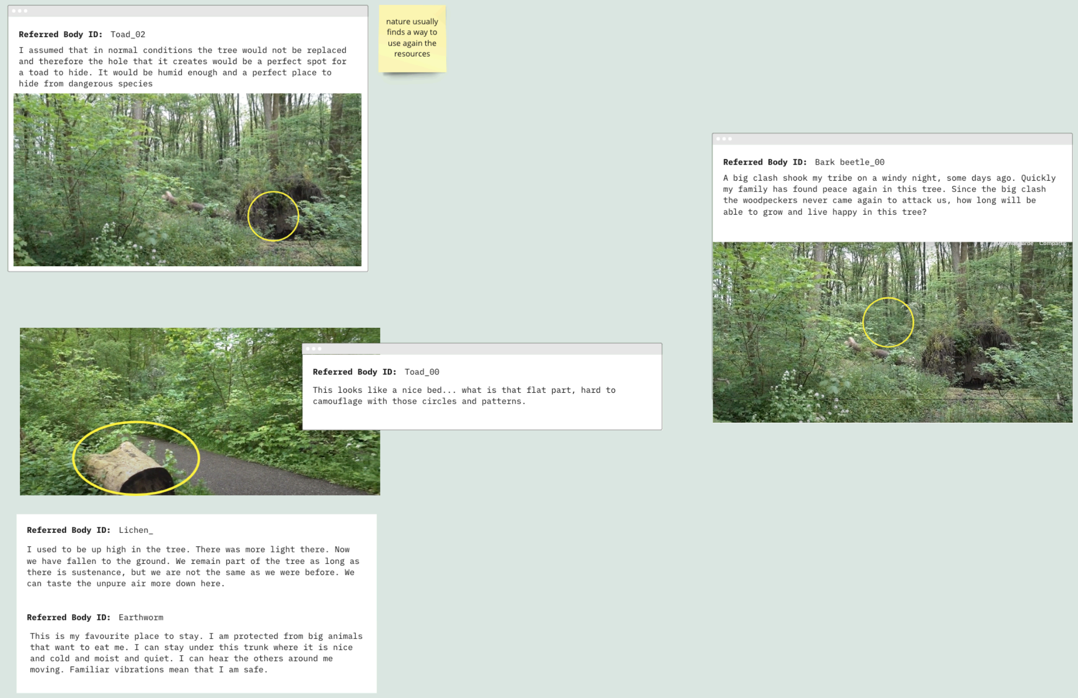


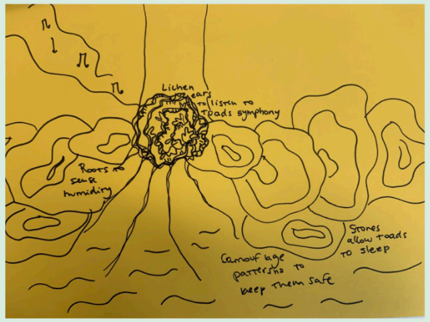
SITUATING

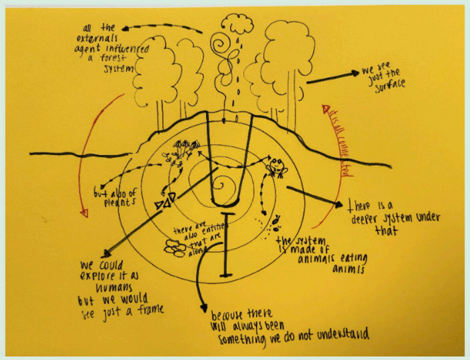
Before the recomposing activity, the participants were asked to make annotations on the forest data through the perspectives of the deconstructed bodies they created. By reflecting on how the same environment can be perceived differently through respective bodies, the objective was to foster participants' recognition of the interconnectedness among different species.



The forest data included tree replacement decision data by Amsterdam municipality (https://maps.amsterdam.nl/vervangen_bomen/?LANG=nl) and footage of the trees that have been recently replaced or granted to be soon replaced.







RECOMPOSING

For the recomposing activity, the participants were asked to first go through the annotations that the other participants had made and then create a body for Vliegenbos. The workshop concluded with individual presentations of the more-than-human forest body that they made and how they would measure the "healthiness" of the urban forest through the body.

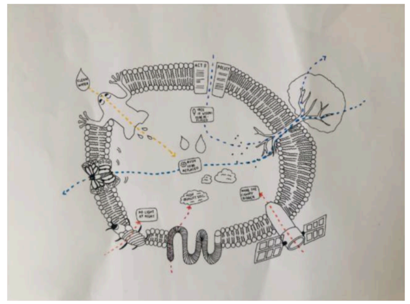
4 Make a more-than-human body for Vliegenbos (30 mins)

Now let's recompose the deconstructed bodies into more-than-human forest bodies. Navigate through the annotations and think about how different bodies are entangled. Can you think of a body for Vliegenbos? What would be the metabolism of this body? What kinds of trade-offs, tensions, or cooperations happen within the body? How can we measure "healthiness" of this body?

Feel free to express however you feel comfortable (e.g. diagram, illustration, writing, etc).

Example (but don't get limited by it!)

Vliegenbos_00



I envisioned an urban forest as a cell with diverse protein receptors on its membrane. Each receptor represents different actors involved in the forest and it allows things that it like or discharges things that it dislikes (e.g. clean water, decision to replant certain trees). First, I thought the bigger the cell is, the healthier it would be. However, I soon thought when there are multiple cells, bigger cells would be greedy ones which are bad for healthiness of the cell community. Then, I thought the activity of such receptors would represent the healthiness of the forest. The more active it is, the healthier the cell would be.

MORE-THAN-HUMAN FOREST BODIES: A LENS FOR MEANING-MAKING

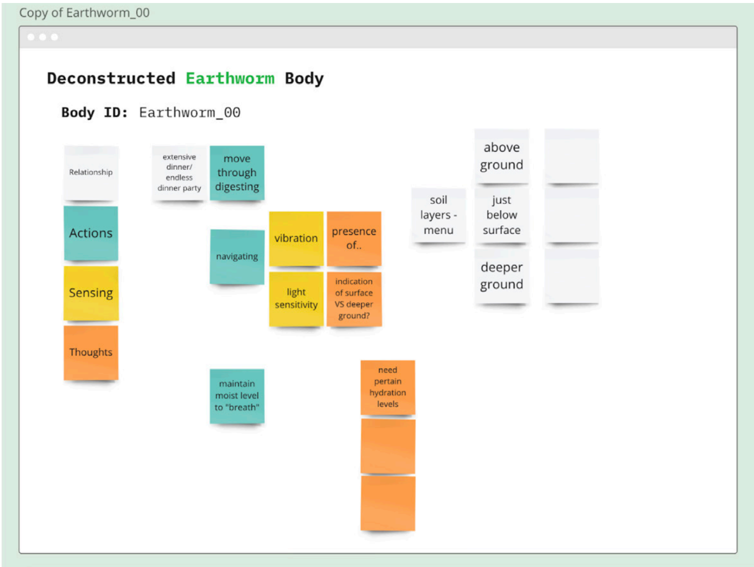
During the workshop, participants were asked to use multiple bodies and more-than-human bodies to understand the forest anew. This chapter illustrates 1) how the participants attuned to nonhuman species through their bodies, 2) how they interpreted the city government's decision on tree replacements from the standpoints of respective species, and 3) how they portrayed forest dynamics in the form of more-than-human bodies.

WORKSHOP FINDINGS (1): ATTUNING

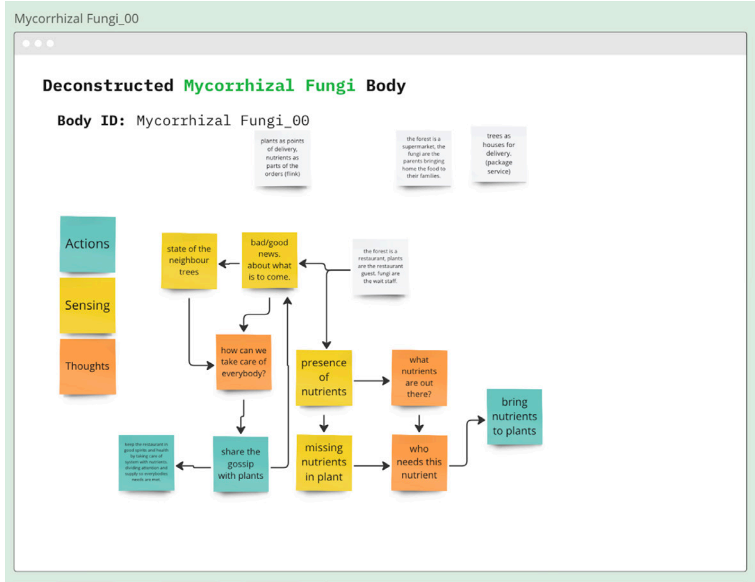
This section highlights selected examples to illustrate how the participants tried to attune to nonhuman species through the lens of the body. In most cases, the participants created metaphors to depict and understand the distinctive spatiality and temporality of each species. The final example shows another approach of carpentry (Bogost, 2012), where the participant created objects that show the world of a single species and assemblage of multispecies.

METAPHOR IN SPATIALITY

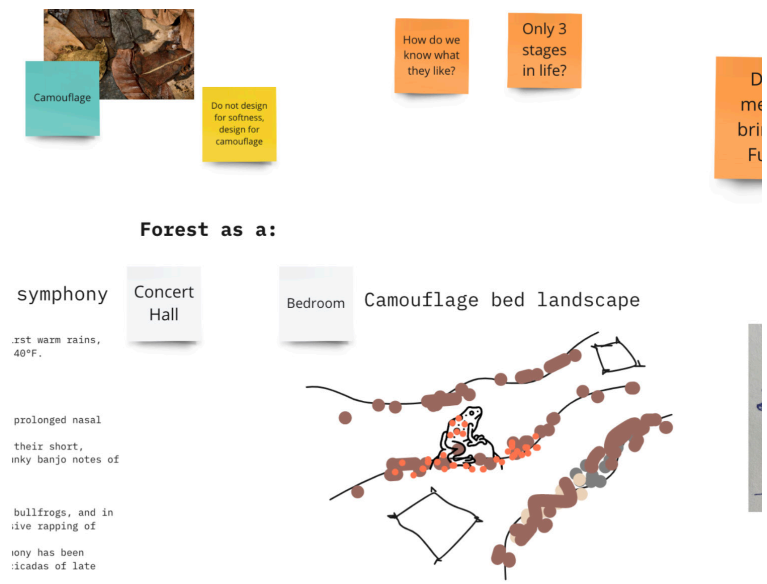
By taking metaphors, distinctive meanings were given to different types, scales, altitudes, or directions of the space. This created unique spatialities for each species.

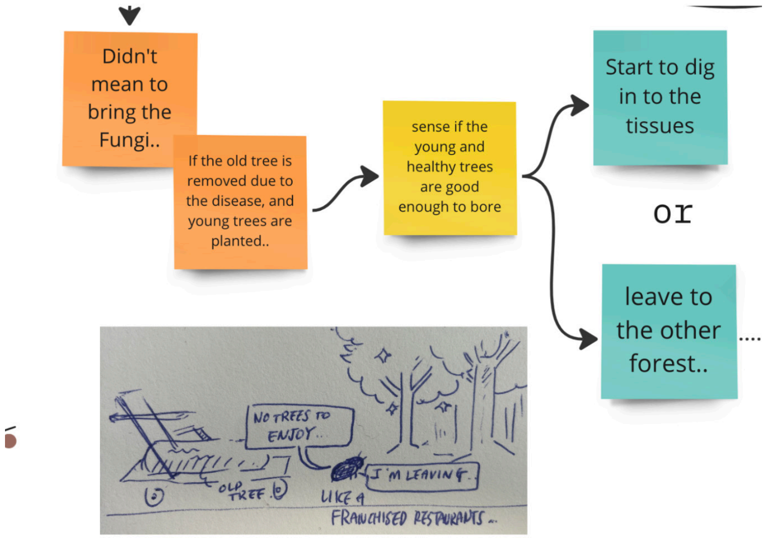


For instance, given that earthworms eat their way through the soil, their movement and navigation were analogized to an endless dinner party. Therefore, different soil layers, such as above ground, just below the surface, and deeper underground, were viewed as menus.



Here, from the fact that mycorrhizal fungi deliver nutrients to trees and plants, the forest is likened to a restaurant where plants are guests and mycorrhizal fungi are servers who deliver the dish. Through this metaphor, the spatiality of the mycorrhizal network was mapped into nodes and links.

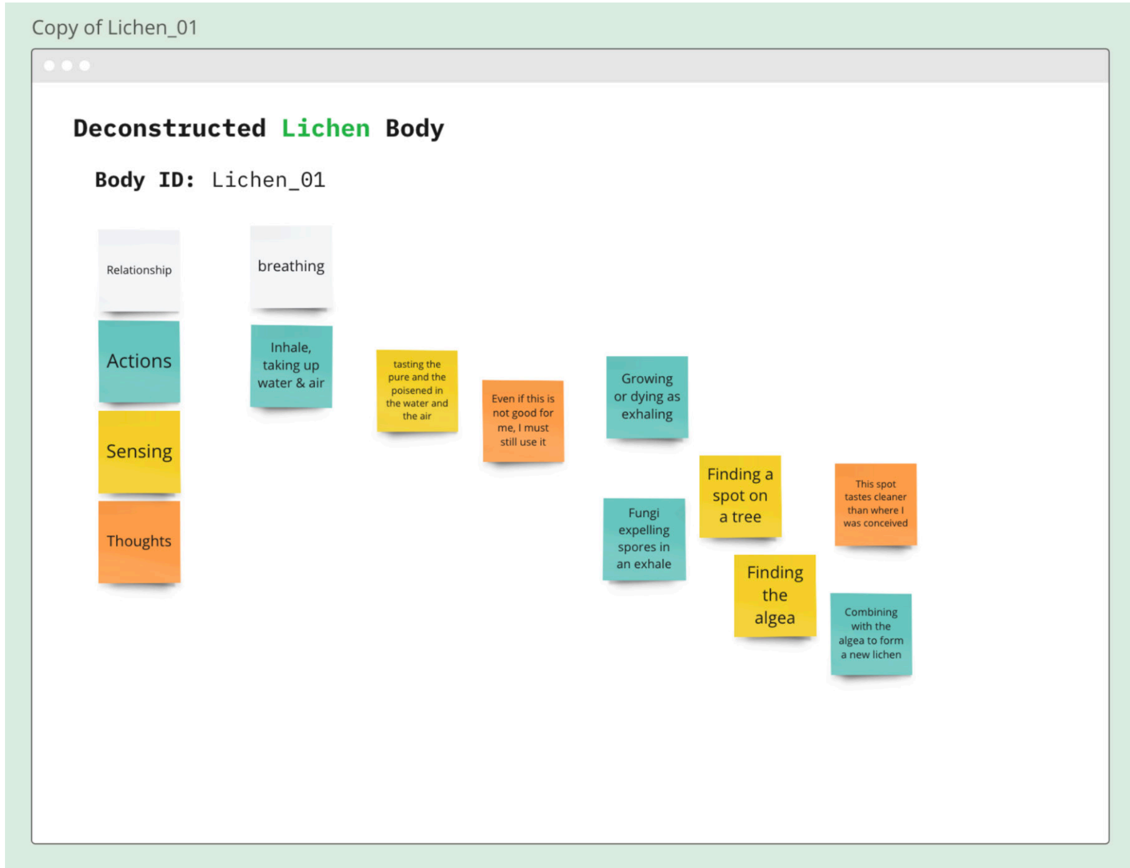




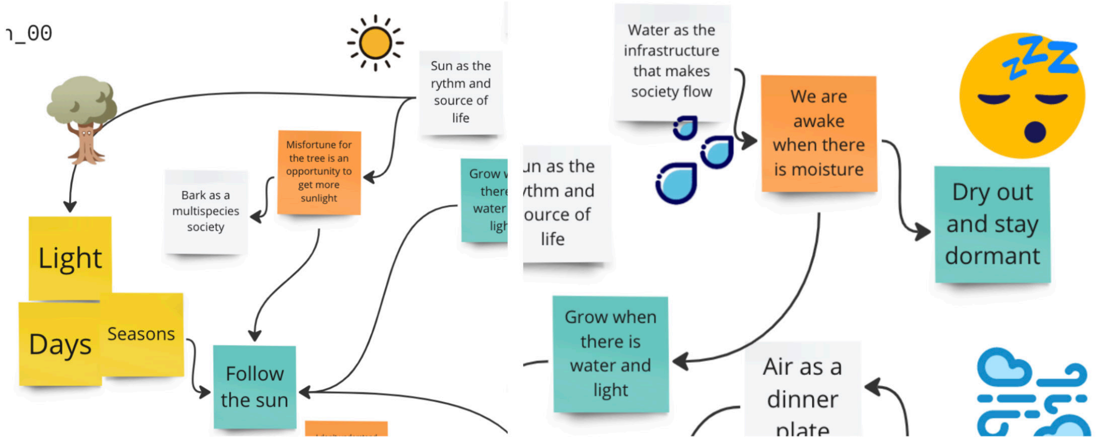
These two examples show how spatiality is affected by the interest of each species. For a toad that prefers a place where it can seamlessly blend into its surroundings, the landscape is categorized based on its resemblance to the toad's skin. In another example of a bark beetle, its relationship with trees was likened to neighborhood gentrification. Since a beetle chooses to leave the forest when there are no longer weak or dead trees to bore into, this cyclic renewal of the forest was analogized to the process of gentrification.

METAPHOR IN TEMPORALITY

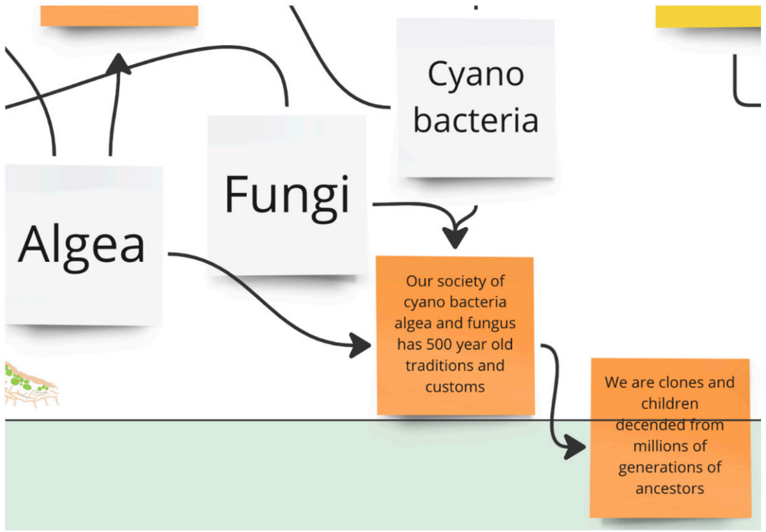
Through the metaphor, distinctive meanings were given to life stages, life cycle, metabolism, heritages, or trajectories. This created unique temporalities for each species.



This example of lichen took the metaphor of breathing to portray its life cycle. Lichen's consumption of water and air was equated to inhaling, followed by growth, reproduction, or death as exhaling. This metaphor highlights the iterative life cycles of lichen that happen across multiple generations.



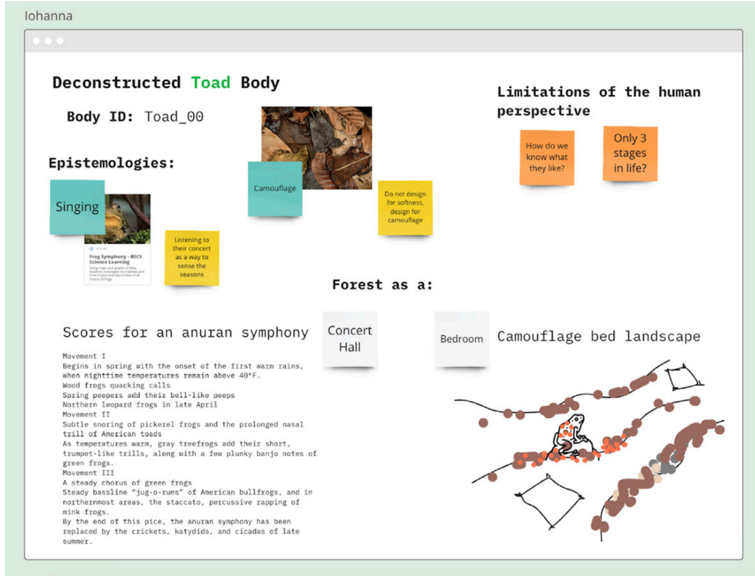
Another metaphor regarding the cyclical temporality was observed where the participant analogized lichen's active status with the sleep cycle. In this metaphor, the moist status of the lichen was viewed as awake while its dormant status in a dry environment was seen as sleeping.



Here, the participant speculated that the society within lichen, composed of cyanobacteria algae and fungus, would have its own traditions and customs that have been passed down for 500 years. This metaphor opens up further queries into what kinds of heritages might have been handed down or what distinctive trajectories might have evolved across generations.

CARPENTRY

Some participants captured emergent phenomena by crafting "things that explain how things make their world (Bogost, 2012)".



Here, the participant focused on two performances of a toad (i.e. singing and camouflage) and created things that bespeak part of a toad's world. From the act of singing, the participant created an anuran symphony. Toads were thought to use the forest as a concert hall where they sing their own melody along with that of frogs, crickets, katydids, and cicadas. The singing performance was conceived as a way for toads to both sense and participate in the changing seasons.

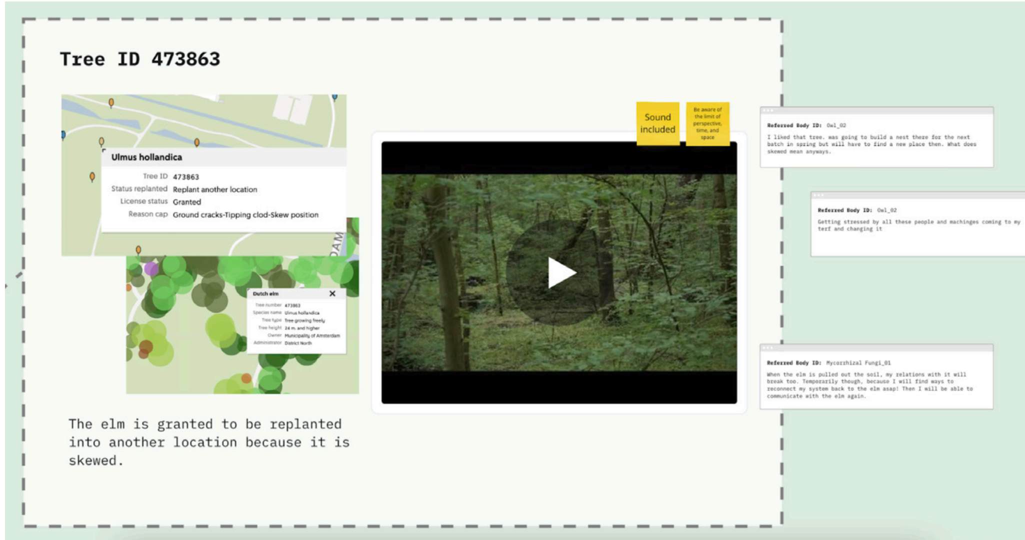
Furthermore, noting that toads prefer to sleep near stones as it is easy to camouflage like stones, the participants conceived of forests as toads' bedrooms. She thought a toad would prefer a bedroom that looks similar to its skin. Therefore, the bedroom for a toad had to be designed for camouflage, not softness (like humans prefer).

WORKSHOP FINDINGS (2): SITUATING

This section illustrates how participants interpreted tree replacement decisions by humans from the perspectives of nonhuman species. Respective temporalities and spatialities of the bodies were used as references to assess the impact of human intervention on individual species. For example, within the specific temporality, some interventions were perceived as temporarily negative but embraceable in the long term, while other interventions were thought to alter the spatiality of nonhumans. This activity affirmed again that any incidents or interventions in the forest ecosystem are highly relational in that they can have either positive or negative consequences

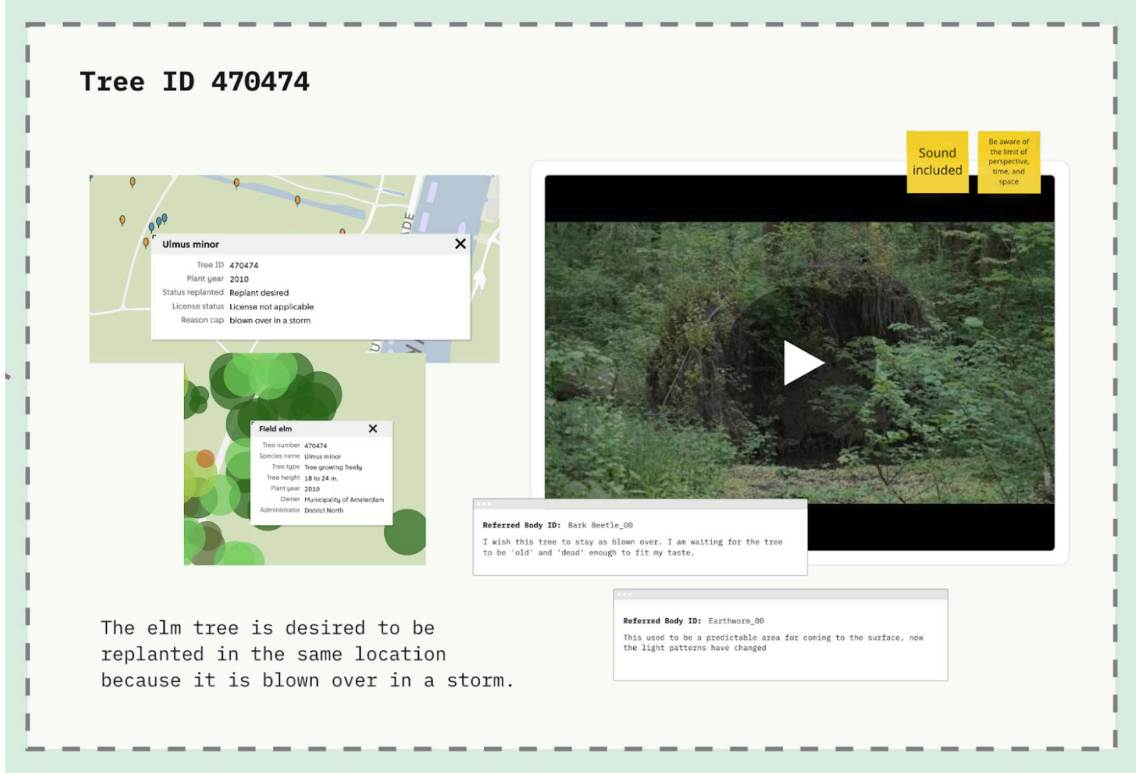
depending on circumstances and perspectives.

From the perspective of lichen, one participant illustrated the potential impact of the path in the forest for the lichens. The good side was that there would be an increase in light exposure but the bad side was that air pollution might occur due to motorized vehicles. This shows that a single intervention can have both good and bad impacts on a single organism.



In this example, mycorrhizal fungi’s temporality was taken into account when assessing the tree replant decision. The participant stated that when the elm tree is pulled up, the fungi’s connection with the tree would also break. However, considering the long lifespan of the fungi, it was speculated that this disconnection would be temporary and would soon try to reconnect with the new tree.

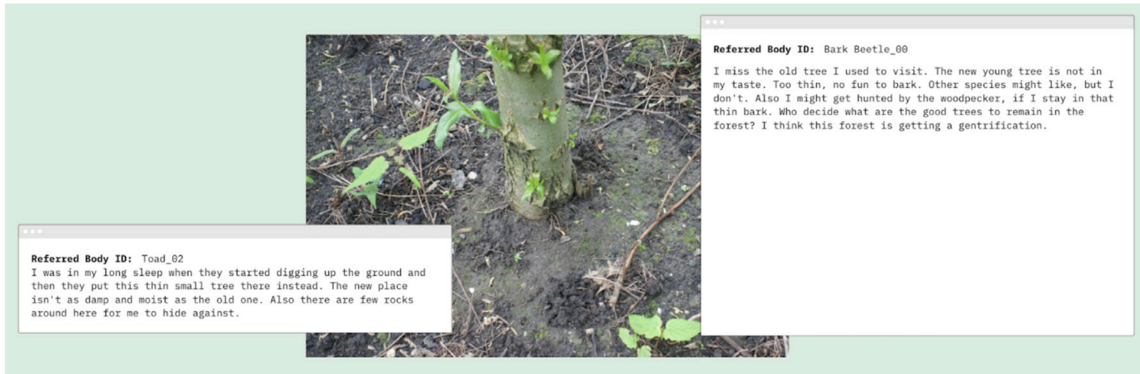
From the perspective of an owl, the replant decision aroused antipathy in that they lost a potential nest. The skewed tree was considered negative to humans for safety reasons but was of little importance to an owl.



The incident of a fallen tree was interpreted differently from the perspectives of a bark beetle and an earthworm. For a bark beetle, the fallen tree was regarded as an opportunity to bore into and make a habitat. For an earthworm, on the other hand, the fallen tree changed the earthworm's spatiality. As the ground was uncovered, the soil layer that had been underground became topsoil, with increased light exposure.

This example of a fallen trunk also triggered a change in the spatiality of lichen. The participant wrote that the lichen used to be up high in the tree where there was more light, but now it has fallen to the ground where the air is more impure.

The same car road has been perceived differently from the perspectives of fungi and tawny owls. Fungi regarded the road as an obstacle hindering its connection with the larger mycorrhizal network, thereby affecting its sensing capability. On the other hand, for a tawny owl, the road and the nearby streetlight were seen as the ideal place to hunt for prey.



WORKSHOP FINDINGS (3): RECOMPOSING

This section illustrates more-than-human aspects of forest data discovered from the outcomes of the recomposing activity. After the activity, each participant explained the reasons for creating such a body for the forest and how they would measure the healthiness of the forest with the body. These discussions were documented and later distilled into the five themes through inductive coding. The first two themes, cyclical temporality, and heritage and trajectory, are particularly pertinent to time, while the themes of balance and turbulence and adaptation are relevant to relations and agency. Lastly, the theme of diverging boundaries applies to both agency and space.

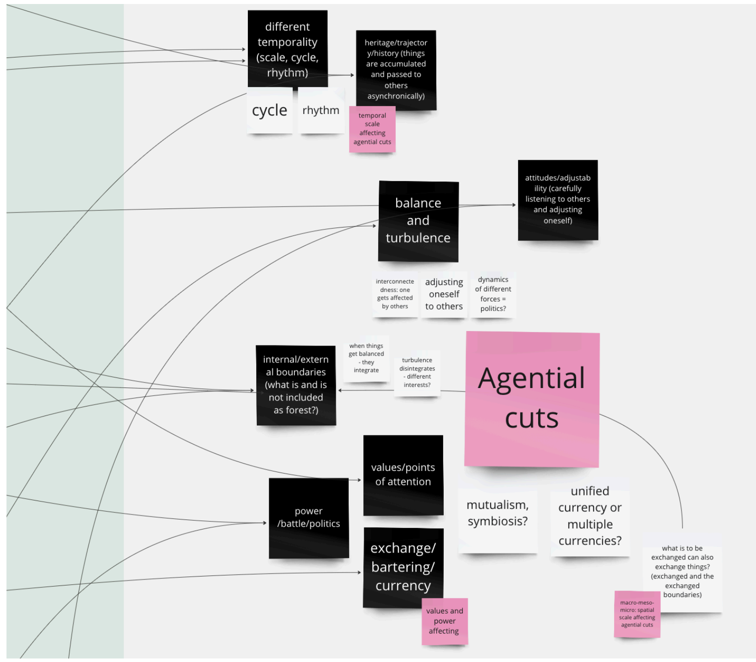
1. Cyclical temporality: Deviating from linear temporality, there exist recurring cycles and rhythms (e.g. life cycle and seasons). These cycles involve roles of not only living organisms but also death. Respective species have their own rhythms of cycle, which are played sometimes in symphony, polyphony, and discord.

2. Heritage and trajectory: Linear temporality also exists in the sense that some things are accumulated and passed down to generations as heritages (e.g. red fox's den). Furthermore, a series of events that happened in the past affect the current and future events which result in unique trajectories (e.g. bark beetle's fungus partnering). These heritages and trajectories are often hard to discern as they happen in various time scales, some much shorter or longer than humans' lifespans.

3. Diverging boundaries: The spatial and agential boundaries of an urban forest were blurred, questioning what is and is not counted as a forest. For example, is the weather part of the forest? Are other forests a hundred kilometers away but connected by mycorrhizae still part of the forest? What is counted as internal and external in terms of the forest? Where does the agency of elm disease belong to? Bark beetle or fungi?

4. Balance and turbulence: The vigorous give and take happening in the forest creates situational arrangements. Some components gather together in certain situations to achieve common goals (e.g. mycorrhiza) and disintegrate when their interests conflict (e.g. resource or space competition). Disturbance is not always negative in that it allows restructuring the forest (e.g. bark beetles and trees).

5. Adaptation: The components of the urban forest carefully listen to each other and adjust themselves according to others.



SCIENTIFIC DISCUSSIONS

To validate the appropriateness of the body as a conceptual lens to capture and interpret forest data from more-than-human perspectives, the five themes were further discussed with data scientists and ecologists.

Above all, the discussions with computer scientists mainly revolved around the feasibility of incorporating these themes into modeling and, if possible, how. While most of the themes could be easily associated with features of ABM, there was a debate on whether the theme of diverging boundaries can be embodied through ABM without contradicting the concept of intra-action[6].

At first sight, the paradigm of object-oriented programming (OOP) which underlies ABM seemed to contradict the concept of intra-action. OOP focuses on modeling real-world entities, concepts, or systems as objects that have attributes and behaviors. Objects are predefined by their classes, which are blueprints encapsulating the information about the attributes and behaviors of the objects. As the concept of intra-action rejects that agency belongs to a certain entity, these two concepts seem to contradict each other. Rather, intra-actions would emerge from entanglements of entities.

After a long debate, the computer scientists pointed out that while the agents themselves may possess internal attributes and capabilities, their agency is also shaped by their interactions and relationships with other agents and their environment. These interactions and relationships between agents give rise to emergent behavior and collective dynamics, which align more closely with the concept of intra-action. Therefore, it was concluded that ABM can embrace the relational aspect of agency by specifying the interactions and relationships between agents. Further details of the discussions can be found in the Appendix.

From the discussion with ecologists, the five themes were further related to ecological concepts and theories. Further details of the discussions can be found in the Appendix.

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6 Intra-action is a term coined by feminist theorist Karen Barad, which challenges the conventional understanding of interaction as a process between separate entities. It emphasizes that entities, both human and nonhuman, are not pre-existing and independent with fixed boundaries, but rather emerge and exist through their entangled relationships.

EMBODIED MEANING-MAKING THROUGH THE BODY

This section illustrates the author's reflection on why the body was particularly appropriate for generating plural interpretations of forest data from more-than-human perspectives. Above all, a body is a ground for embodied subjectivity. The bodily sensations, emotions, and movements actively shape the subjective reality. In other words, the body becomes the site for a "lived world" where the experience and interactions with the world are actively shaped through sensory inputs and motor outputs. Through the body, one perceives the world and acts upon it. Sensory systems gather information that shapes one's relationships and understanding of the world, while motor capabilities and physical constraints influence one's ability to act, thereby shaping the way one manipulates and responds to the environment. Understanding these sensorimotor systems can be a starting point for attuning to the worlds of others.

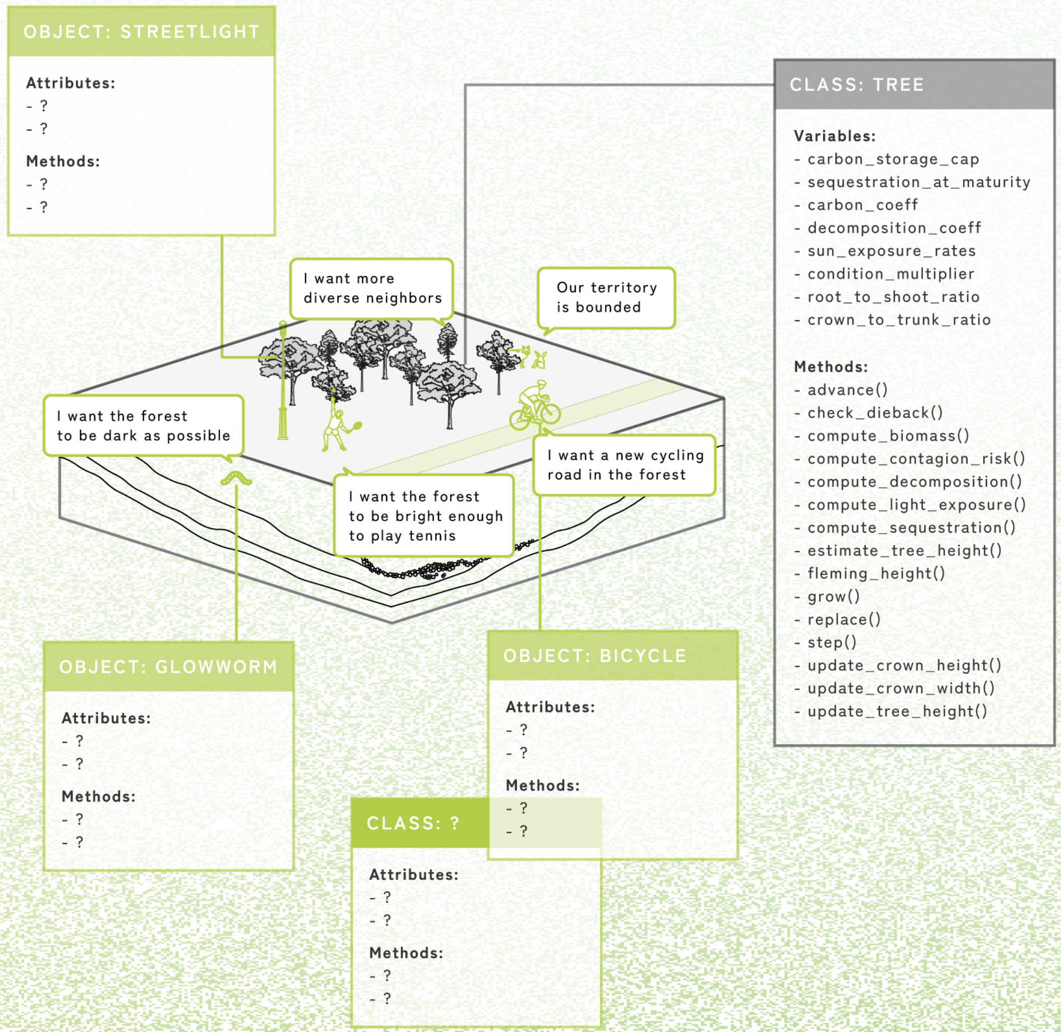
The fact that the body is in a constant state of flux also opens up other dimensions of meaning. For one, the physical abilities and thus interactions with the world change over time, as one grows and goes through the aging process. This generates a unique trajectory where one continuously recalibrates its capacity and adjusts its way of using the body. Moreover, the body gets remolded through exchanges of substances, energies, and information with its surroundings. Situated within specific environments, the body interacts with other bodies. These diverse and distinctive bodies may harmonize and coexist with each other or discord and necessitate negotiation of contradicting realities. This fluid boundary of the body facilitated participants in conceptualizing more-than-human bodies, where agency emerges from interactions with multiple bodies.

Finally, the more-than-human bodies accommodate the concept of trans-corporeality (Alaimo, 2018) where the body is seen as a part of the interconnected web, rather than

A discrete, bounded entity. By noticing these permeability and interdependencies, the more-than-human bodies facilitate the reconception of health and responsibility to care. Multiple bodies open up gateways to generate plural definitions of what a healthy forest is. Personal experiences in maintaining health and taking care of one's own body eased the participants in envisioning alternate ways to maintain the forest healthy.

REDESIGNING THE COMPUTATIONAL MODEL

This chapter showcases the modeling of sample cases, referring to the five more-than-human themes of forest data. Three specific cases were chosen from the workshop. The cases were presented in the form of state diagrams.



MODELING CASES

From the entanglements discovered through the workshop, the three cases were chosen to be modeled, considering the different scales at which each case operates and the diversity of more-than-human themes they cover. The first case explores the impact of individual behaviors at a micro scale, focusing on earthworm burrows and their influence on soil conditions that extend beyond the lifespan and habitat range of the earthworms themselves. Furthermore, it shows how storm or tree replacement by humans might alter the spatiality of earthworms. The second case questions the agential boundaries of Dutch elm disease, underscoring that neither the bark beetles nor the fungi alone can cause the disease. It also touches on unique trajectories of symbiosis between bark beetles and fungi in that the agency of the association can significantly differ depending on the types of the partnered fungi. The last case attempts to explain early spring by redefining spring as a collection of diverse biological clocks at macro scale, rather than a fixed range between two calendar dates.

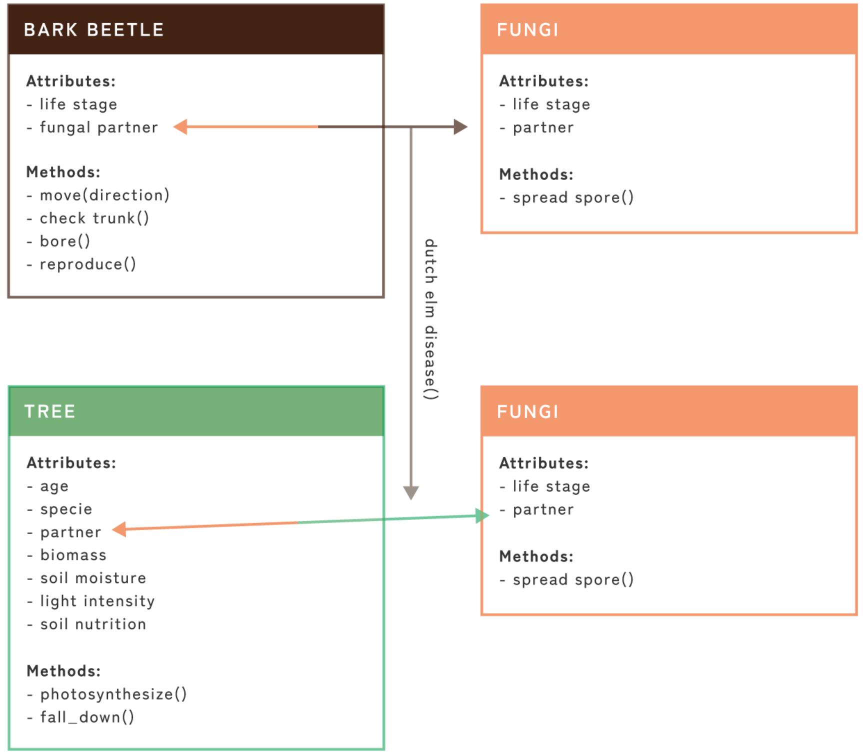
MICRO

BALANCE AND TURBULENCE

HERITAGE AND TRAJECTORY

EARTHWORM'S BURROW AND SOIL CONDITION

Earthworms play a crucial role in shaping soil conditions through their burrowing activities. As these organisms tunnel through the soil, they create channels and passageways that facilitate the movement of air, water, and nutrients. This allows for better drainage, reduces the risk of waterlogging, increases soil aeration, promoting the growth of beneficial microorganisms, and facilitates nutrient cycling. Additionally, earthworms' consumption of organic matter and subsequent deposition of their castings further enriches the soil with nutrients, enhancing its fertility. This contributes significantly to the overall health and quality of soil, benefiting plant growth and ecosystem functioning.

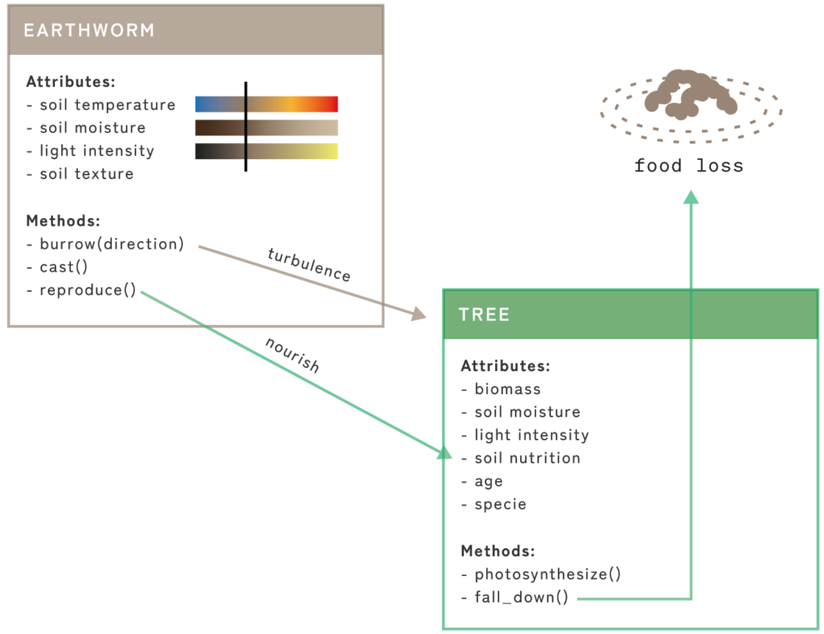


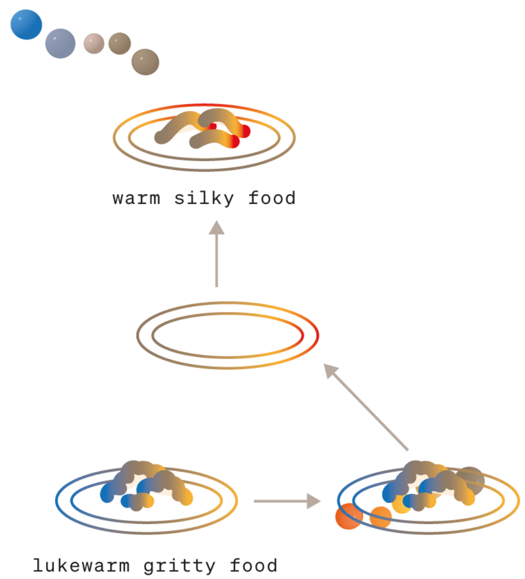
MESO

DIVERGING BOUNDARIES

BARK BEETLE-FUNGUS ASSOCI-ATION AND DUTCH ELM DISEASE

Dutch elm disease is a fungal disease that is detrimental to elm trees. Its primary cause is thought to be Ophiostomatoid fungi transmitted by bark beetles. The disease spreads when infected beetles carry fungal spores from infected trees to healthy ones, introducing the fungus into the tree's vascular system. Once inside the tree, the fungi colonize and block the water-conducting vessels, disrupting the tree's ability to transport water and nutrients. As a result, the tree's leaves wilt, turn yellow, and eventually die.Dutch elm disease has had a significant impact on elm tree populations worldwide, remaining as a significant challenge for elm tree conservation and management.





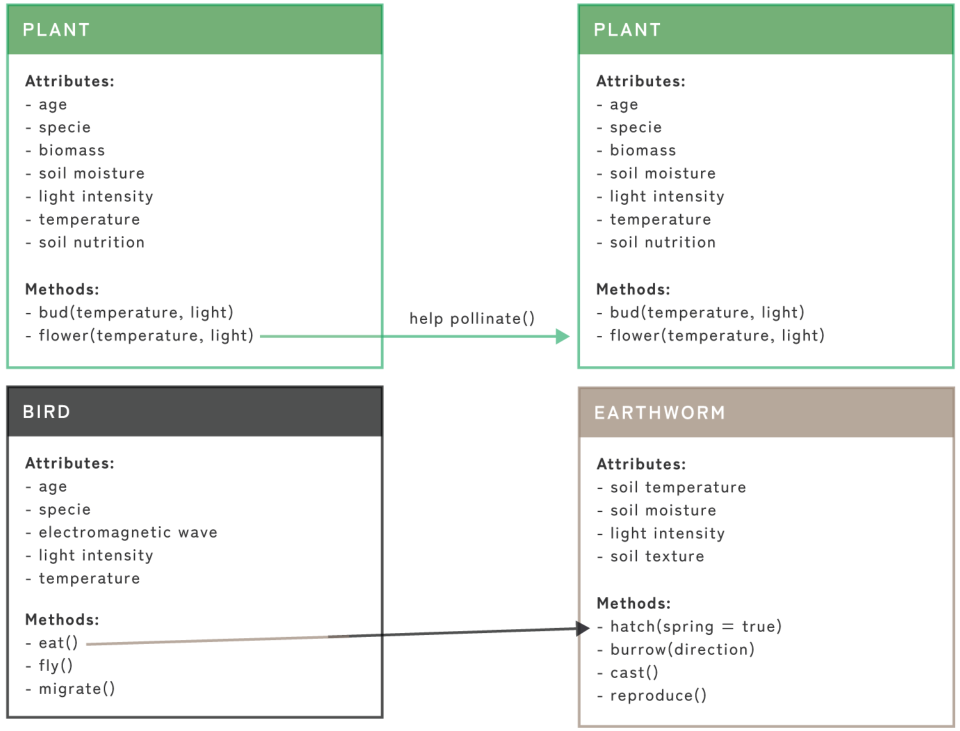
MACRO

ADAPTATION

CYCLICAL TEMPORALITY

EARLY SPRING AND CLIMATE CHANGE

A season can be seen as a collection of diverse phenological relationships between plants and animals. This synchrony in seasoning timing of life-history events enables maintaining the balance and as a result manifests as a season. For example, the arrival of a migratory bird species should be timed to match the seasonal peak of its main food source so that the predator species can survive and the population of prey can be balanced. However, due to climate change, the number of mismatches within the spring is increasing. On one hand, environmental cues, such as temperature, are outpacing the rate at which organisms are able to adapt. On the other hand, biological clocks of organisms are becoming misaligned.



MORE-THAN-HUMAN FOREST BODIES AS A STRONG CONCEPT

Throughout the workshop, the notion of body helped the participants navigate and understand the endless web of connections in the forest. By attuning to the existing bodies or crafting imaginary more-than-human bodies, these porous conceptual boundaries provided corporeal foundations to be grounded while allowing room to generate and encompass diverse meanings. In particular, the body, itself being situated in ever-changing temporal, spatial, and agential scales, facilitated the participants to stretch their understanding of the urban forest in multiple dimensions. Given this generativity throughout diverse scales, I decided to further explore whether more-than-human forest bodies can serve as a strong concept (Höök and Löwgren, 2012).

WHAT IS A STRONG CONCEPT

A strong concept refers to generative intermediate-level knowledge that plays a direct role in the creation of new designs. They are design elements abstracted beyond particular instances that have the potential to be appropriated by designers and researchers to extend their repertoires and enable new particular instantiations. Höök and Löwgren (2012) propose a strong concept in interaction design to have the following characteristics:

- It concerns the dynamic gestalt of an interaction design, that is, its interactive behavior rather than its static appearance.
- It resides at the interface between technology and people. It is a design element, a potential part of an artifact, and at the same time, it speaks of a use practice and behavior unfolding over time.
- It carries a core design idea that has the potential to cut across particular use situations and perhaps even application domains.
- It resides on an abstraction level above particular instances, which means that it can be realized in

CONSTRUCTING THE BODY AS A STRONG CONCEPT

In order to take the body as a strong concept, I illustrate its construction process as indicated by Höök and Löwgren (2012).

1. SOURCE

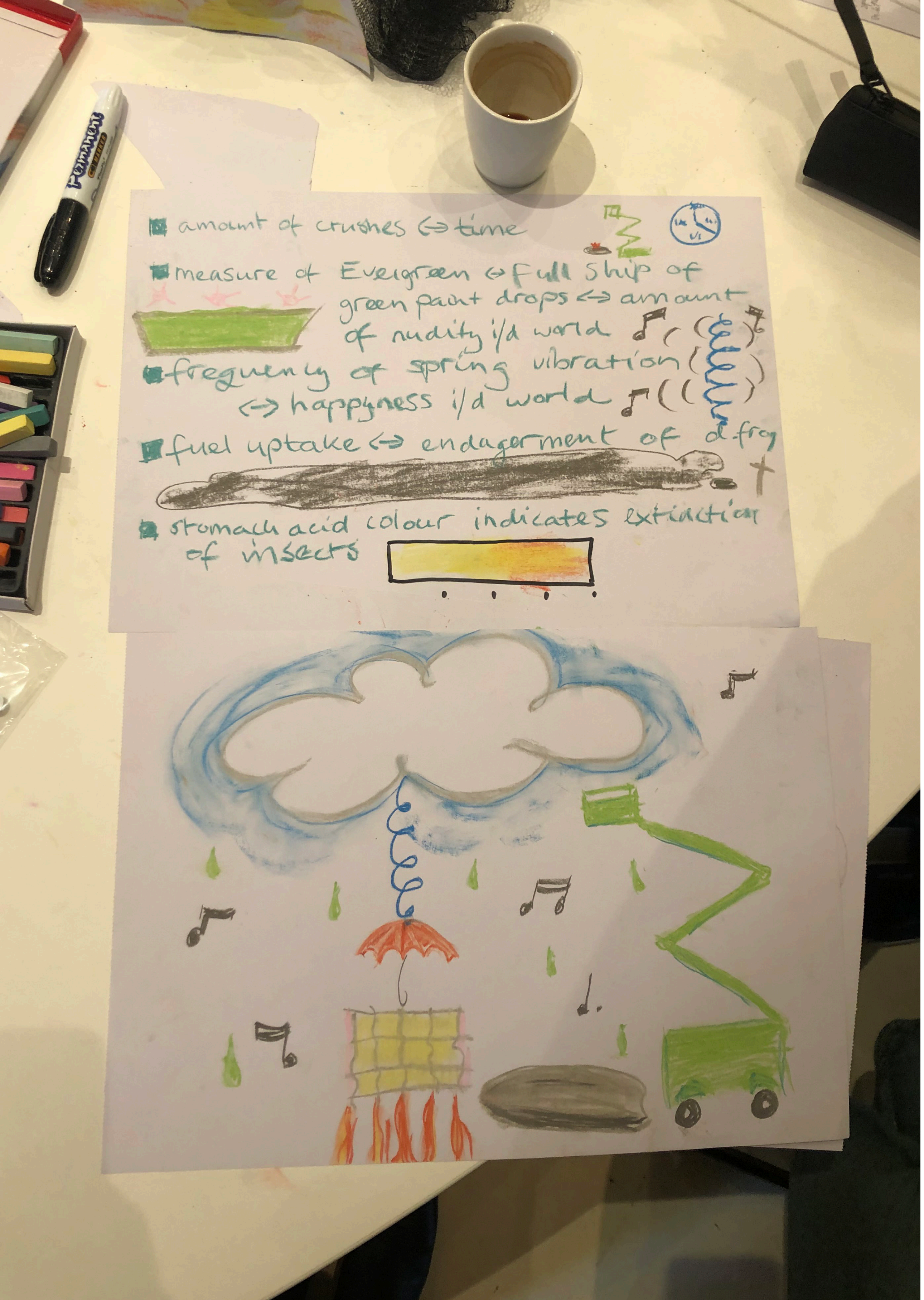
The source of a strong concept could be an instance(s) designed to respond to a particular existing use situation, to explore a possible use situation, or to concretize a specific theory of human behavior. In this project, prior to the workshop organization, there were instances that became the primary source of the body as a strong concept.

On the 22nd of April, I participated in the Shapeshifters workshop by Cruda Collective, where the participants were invited to make a post-natural[7] bestiary[8] to measure the world anew. By taking the body as a tool for measuring space, and therefore a site of understanding and being in the world, we were asked to create alternative hybrid bodies that enable multiple understandings and beings within the world. Two of the workshop outcomes later became the core inspirations for the more-than-human forest bodies workshop.

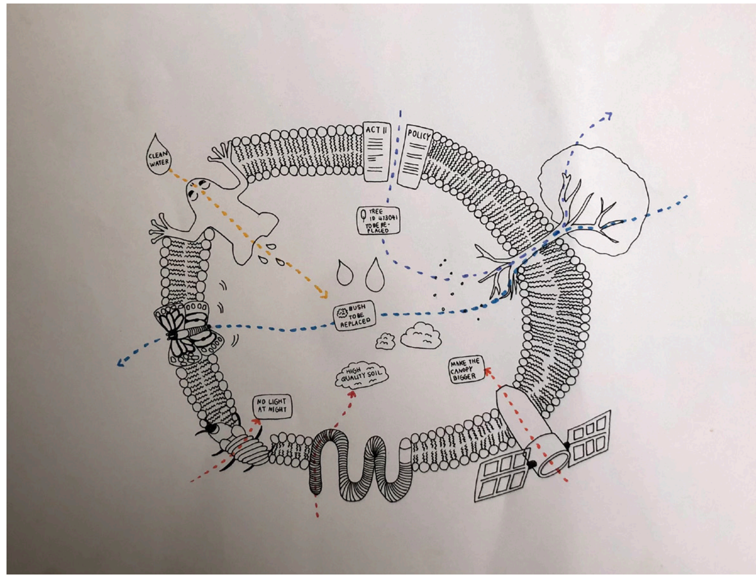
The first instance was the deconstructed body of a frog made by one of the participants. A frog being her favorite animal, she first deconstructed the complexity of a frog and embodied it in the form of the deconstructed body. "Deconstructed" here refers to reinterpreting the object by taking it apart and examining its constituent parts. In

7 The post-natural refers to a condition by which there is no divide between nature and culture; a condition through which the natural is redefined and re-distributed to fit many worlds (Cruda Collective, 2023).

8 A bestiary is a compendium of beasts which originated in the ancient world. It was popular in the Middle Ages in illustrated volumes that described various animals and even rocks. An illustration of each beast was usually accompanied by a moral lesson (Cruda Collective, 2023).



the image on the left, the frog's body was deconstructed to combust fuel to move the umbrella linked to the cloud and thereby generate rain and croaks. By integrating a cloud as a part of a frog's body, the bodily boundary of a frog was blurred and expanded to embrace the rain. Then, the participant used the deconstructed frog's body to measure the phenomena in the world, such as time and the happiness of the world. For example, she thought the frequency of a spring that connects the umbrella and the cloud represents the happiness of the world. She thought the more a frog eats and thereby the more the umbrella moves up and down and the cloud generates rain and croaks, the happier the world would be.



Another instance is the body of the urban forest that I made. Taking a forest as a single organism, I wanted to craft a body for the forest to measure things that can be captured within the entanglement. I viewed an urban forest as a co-produced site where both human and nonhuman actors actively take up what they prefer and let go of what they dislike. So I took a metaphor of a cell membrane where each actor is represented as a receptor which only opens up under certain circumstances.

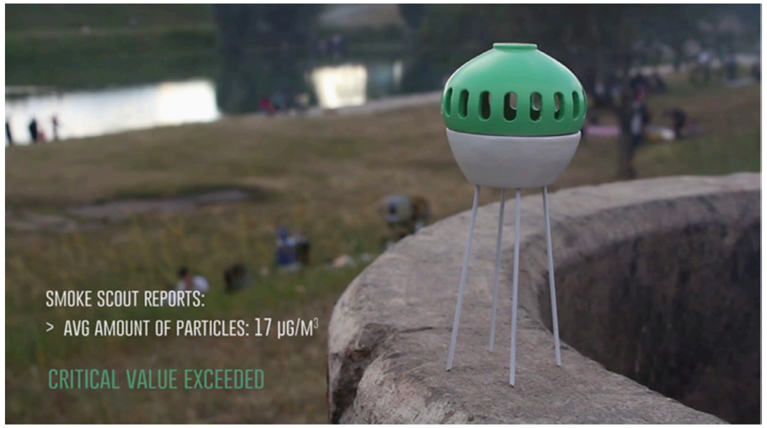
2. HORIZONTAL GROUNDING

The next step was horizontal grounding, which is to relate similar concepts to comprehend the scope of applicability of the strong concept by comparing their similarities and differences.

One of the similar strong concepts is Summer Scouts by Meusburger and Pichlbauer (2016). With the collection of sensors, Meusburger and Pichlbauer (2016) attempted to capture a shared feeling among the urban community, an aspect of city life that can be perceived by its members but remains concealed to an outside observer, and the pragmatic grid of common sensing facilities with the collection of sensors. They were particularly interested in so-called communal emotions, for instance, a sense of the beginning of summer. For them, neither a certain date, the temperature nor the weather determined the beginning of summer.

Instead, they noted the collection of little changes, actions, and habits in the life of the individual that set the mood not only for itself but also influenced the other parties of the community to adapt and behave accordingly, setting a chain reaction of behavior changes and adaptation into motion. Named Summer Scouts, sensors around the city detect seven key signs of summer: tree pollen, Biergarten noise, barbecue smoke, sunscreen in pool water, mosquito movement, ice cream scooping, and window-opening on public transit. Once every one of these measurements exceeded a certain threshold, the Summer Scouts proclaimed that summer had officially arrived.

The similarity I found between Summer Scouts and more-than-human bodies is that both attempt to capture a communal sense that is too nuanced and relational to be reduced into simple numeric measures. The difference lies in their ways of capturing those feelings. While Summer Scouts determine the beginning of summer through unanimity among each sensor dedicated to respective events, more-than-human bodies open up what a healthy forest is by exposing perpetual negotiations among diverse bodies in the forest. Furthermore, it is different that the consensus of Summer



Brink, N. (2015). Measuring barbecue smoke wafting through the air [Photograph]. Designboom. https://www.designboom.com/design/summer-scouts-mia-meusburger-johanna-pichlbauer-06-02-2015/

Brink, N. (2015). Bugs per meters cubed [Photograph]. Designboom. https://www.designboom.com/design/summer-scouts-mia-meusburger-johanna-pichlbauer-06-02-2015/

Scouts is made within humans' senses and more-than-human bodies expand their sensory inputs and actional outputs to the realm of the nonhumans.

3. VERTICAL GROUNDING

The third step towards making a strong concept is called vertical grounding which aims to broaden its empirical base and deepen the theoretical underpinning.

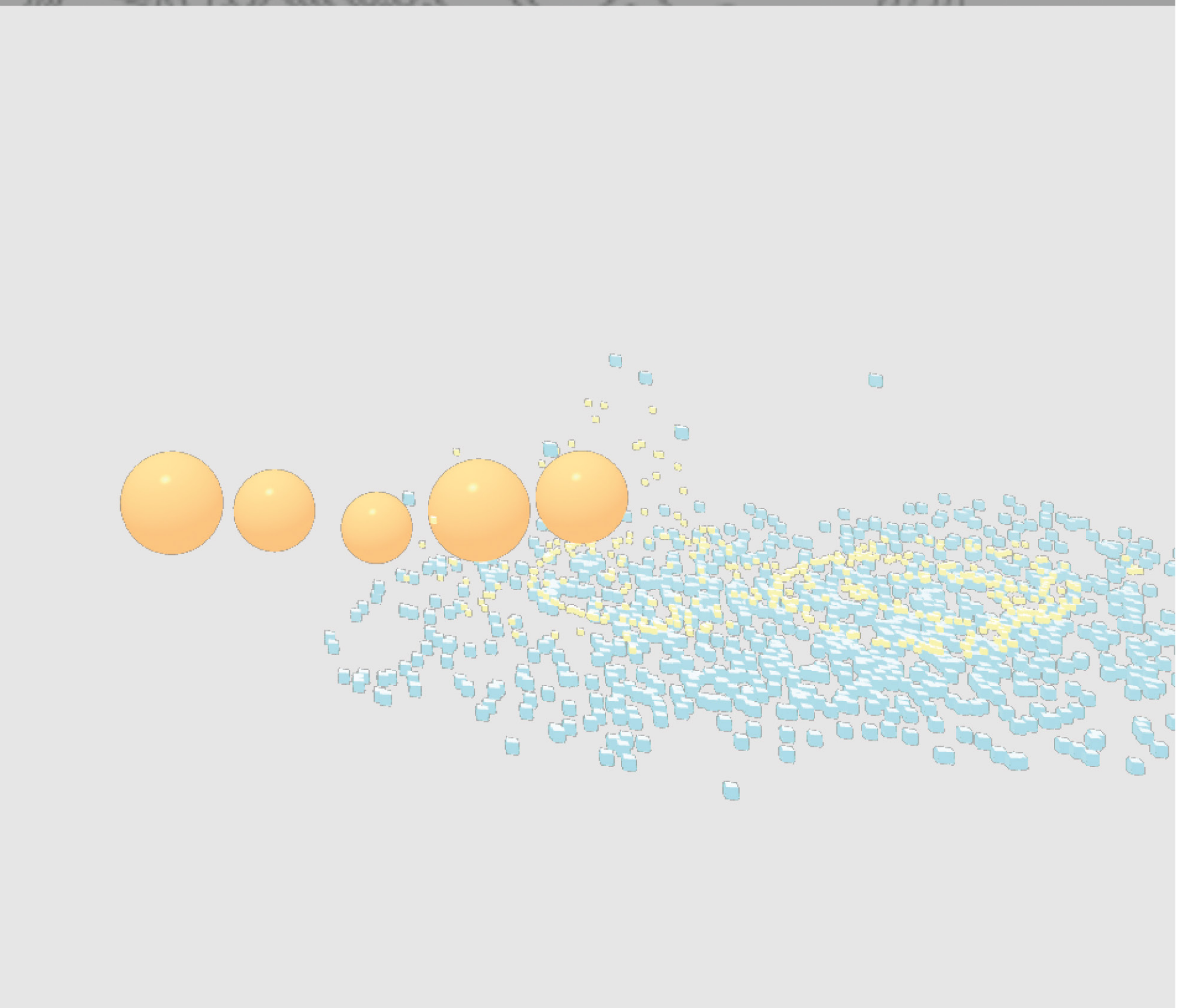
One of the known instances of more-than-human bodies is Forlano's (2017) description of becoming a disabled cyborg body by adopting a glucose monitoring device and an insulin pump to manage diabetes. She illustrates how she and her medical devices have been inseparable through mutual acts of care; she changes their batteries, and in return, they keep her insulin levels in balance and ultimately keep her alive. This hints that the strong concept of more-than-human bodies might be further used to design acts of mutual care or even novel strategies for collaborative survival.

Furthermore, the notion of more-than-human bodies has the closest links to Karen Barad's theory of agential realism, which insists that the universe comprises phenomena that are ontologically inseparable from intra-acting agencies. This refreshes that forests consist of entangled agencies and our attempts to understand these entanglements with the aid of digital technologies is a material discursive practice. In other words, the technologies (in this project, digital twin simulation) involved in observation are inseparable from what is being observed since matter and meaning do not pre-exist but rather are entangled with each other. Based on this material discursiveness, crafting diverse corporeal bodies is expected to facilitate making plural meanings of forest data. These plural interpretations of forest data would enable people to decenter themselves from anthropocentric relationships with and values against urban forests and thereby reconfigure themselves as part of a broader urban ecosystem and their roles in collaborative survival.

This also resonates with the concept of "data sense" by Deborah Lupton (2019), which refers to how individuals make sense of and interact with data in their everyday lives. It encompasses how people perceive, interpret, and use data to understand their environment, make decisions, and construct their identities. Lupton (2019) underscores that our engagement with data is embodied and multivalent. The word "embodied" suggests that our bodily sensations, emotions, and physical contexts shape our understanding and interpretation of the data, and the "multivalent" aspect means that data can have multiple interpretations. Different individuals or communities may interpret the same data differently based on their perspectives, experiences, and values. Therefore, data should be seen as a complex and dynamic construct that can be expanded to various meanings, rather than being a singular, objective entity.

4. VALIDATION

The final step in constructing a strong step involves validating whether it is contestable, defensible, and substantive. According to Höök and Löwgren (2012), a strong concept is contestable if it is novel to the interaction-design research community and is defensible if it is grounded empirically, analytically, and theoretically and if the research process is rigorous and criticizable. Lastly, it is substantive if it is deemed relevant to the interaction-design research community, if it can be argued to contribute to better interaction design, and specifically if it is generative in the sense that it can be used to create new instances. This will be further elaborated through the following chapters.



DESIGNING AND PROTOTYPING THE SIMULATION

Utilizing the more-than-human bodies as a strong concept, this chapter explores our interactions with forest data towards more-than-human forest governance. In the previous chapter, I attempted to construct the more-than-human bodies as a strong concept. More-than-human bodies refer to the notion of blurring boundaries of one's body(ies) and being entangled with other bodies by adopting plural temporality, spatiality, and agency. It can be seen as a counterreaction to the prevailing binaries between nature/culture and human/nonhuman. By deconstructing and recomposing oneself as a part of a broader ecosystem, it aims to enable users to navigate through diverse temporal, spatial, and agential scales.

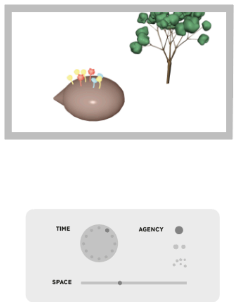
IDEATION

CONCEPT

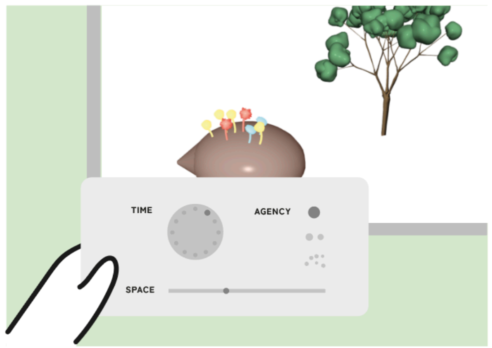
The experience starts with exploring and interpreting the data through diverse forest bodies and concludes with negotiating humans' interventions on behalf of the bodies in the forest. The image below is the initial storyboard and wireframe.

SIMULATION DISPLAY (TOUCHDESIGNER)

SMARTPHONE CONTROLLER (P5JS)



Visitors first get to know entanglements in urban forests through posters (or booklet).



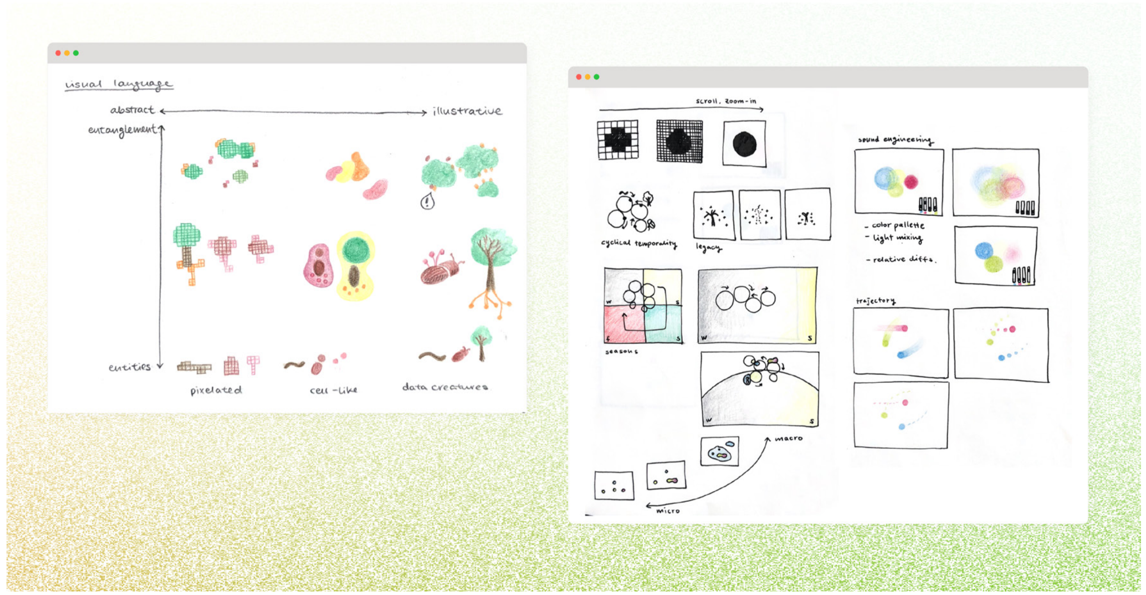
Visitors navigate different temporal, spatial, and agential scales of the urban forest.

Visitors plant or remove trees and explore their simulated futures.

VISUAL LANGUAGE EXPLORATION

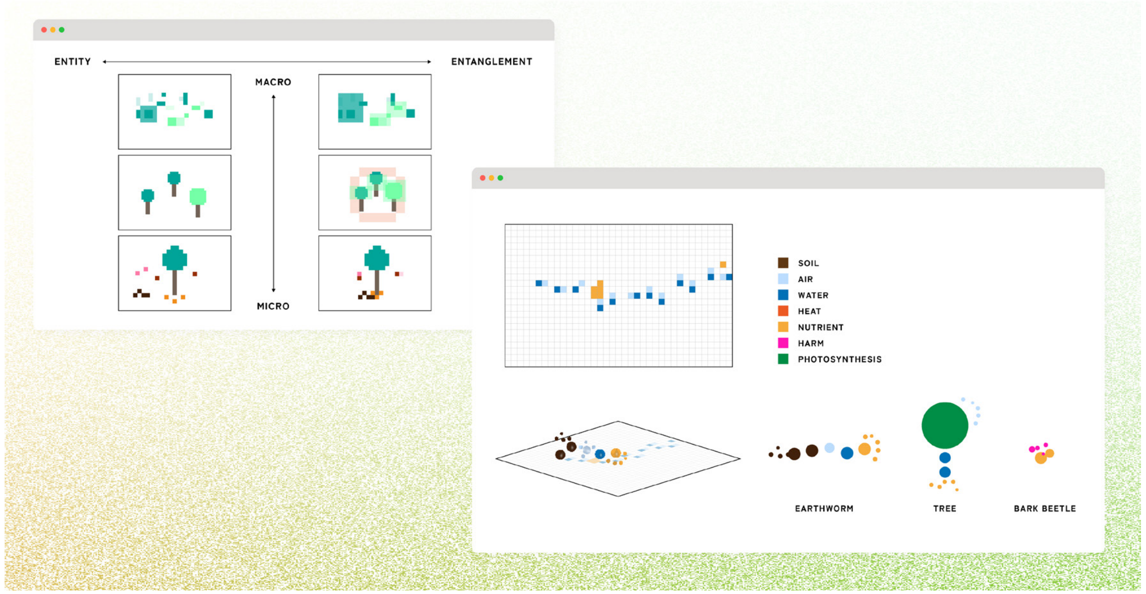
The ideation for visual language took two factors into consideration: expressibility and scalability. Above all, the design system should be able to flexibly express both quantitative and qualitative data. Moreover, it had to be scalable so that it could express changes in different scales in a unified language.

VISUAL LANGUAGE IDEATION



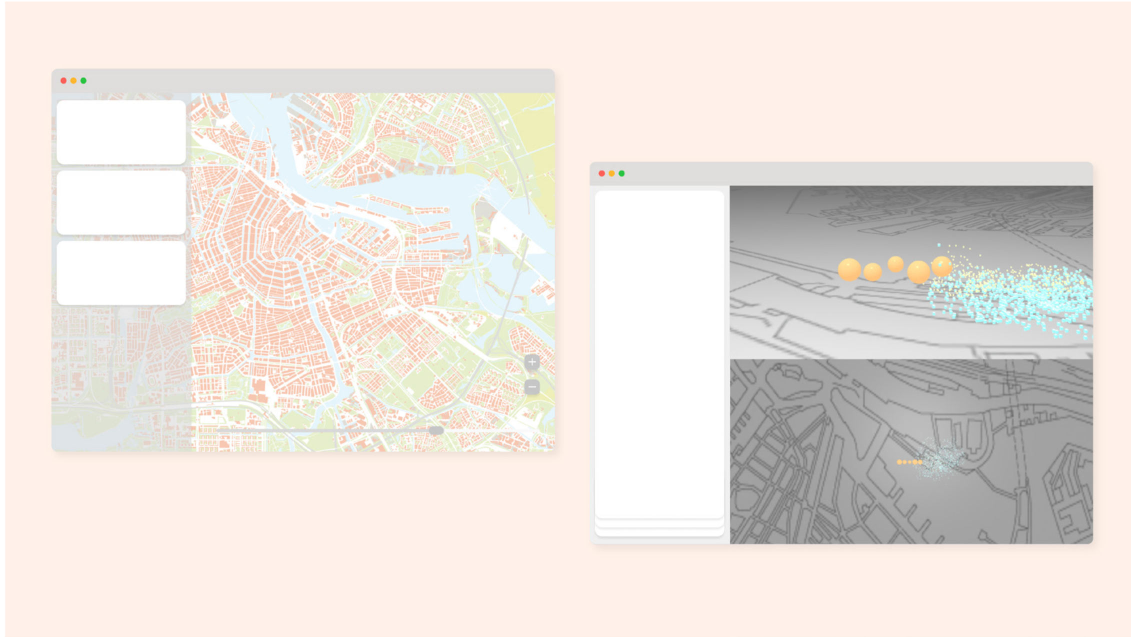
Given that the metaphor of body significantly helped people to understand agencies that arise from different scales, the concept of the data creature was chosen to "subjectify" historical events within their own time and space scale. However, while the figurative shapes of the body were suitable for delivering qualitative research insights, such as characteristics and stories of each agent, quantitative data such as soil moisture, light intensity, or temporal rhythms needed more scalable modular units to be displayed. This tension between modular geometries and pictorial illustrations became the inspiration for the 'data creature' concept where the data points comprise swarm-like bodies.

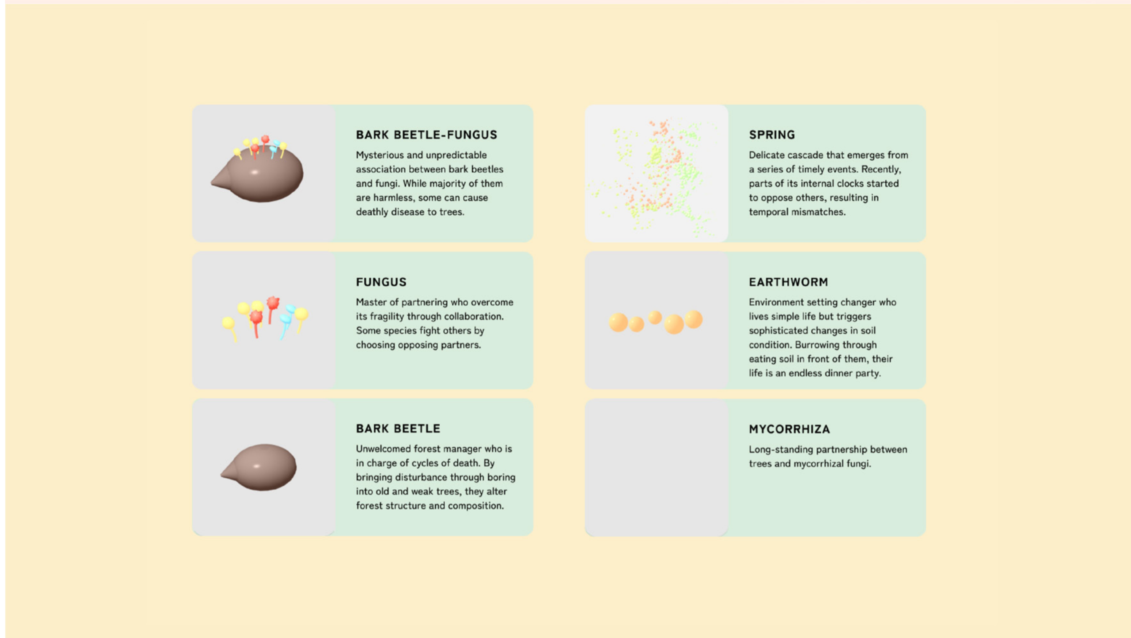
FROM DATA POINTS TO DATA CREATURES



PROTOTYPE 1

By applying the visual language of data creatures in the initial concept, the first prototype was made. The prototype showed four two types of main screens where people can get to know about each agent and navigate different spatial scales.

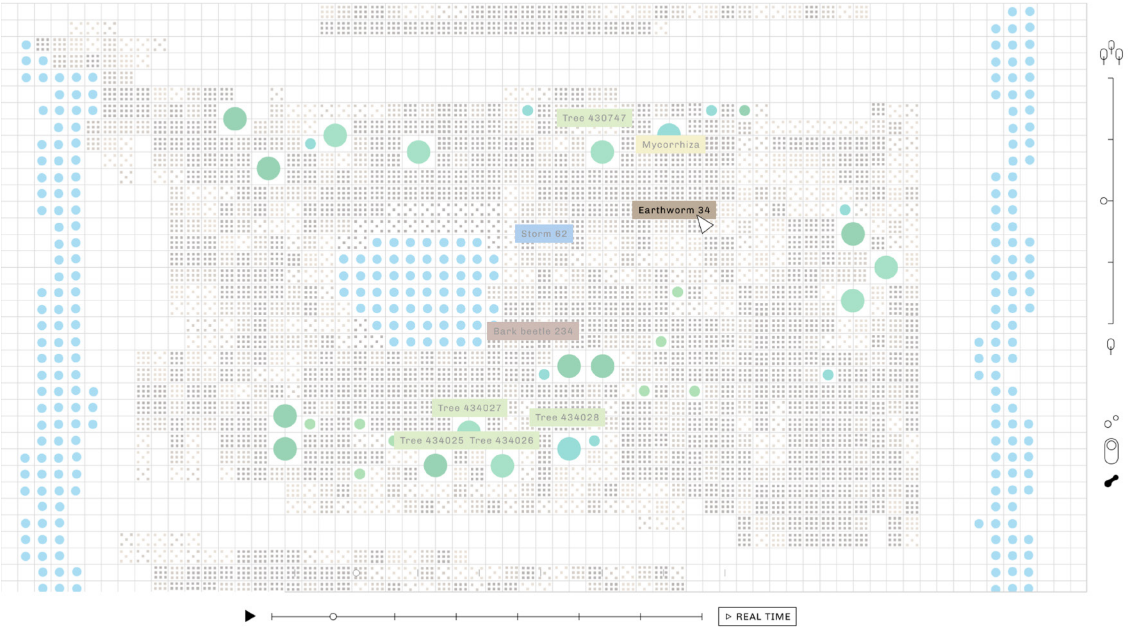




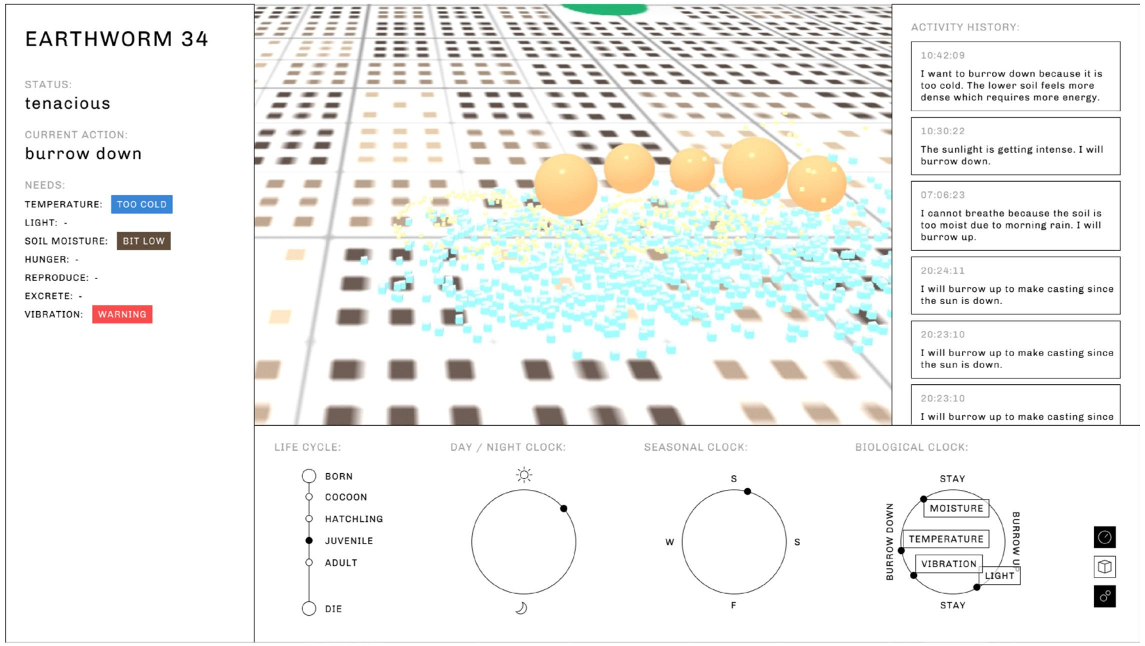
While the 3D real-time rendering of the data creatures intrigued people's interest, most people had difficulty figuring out the association between data points in 2D maps and the 3D creatures. The impression of a realistic map seemed to be discordant with fictional characters. Furthermore, they wanted to know more about the characteristics and stories of each agent to be attuned.

PROTOTYPE 2

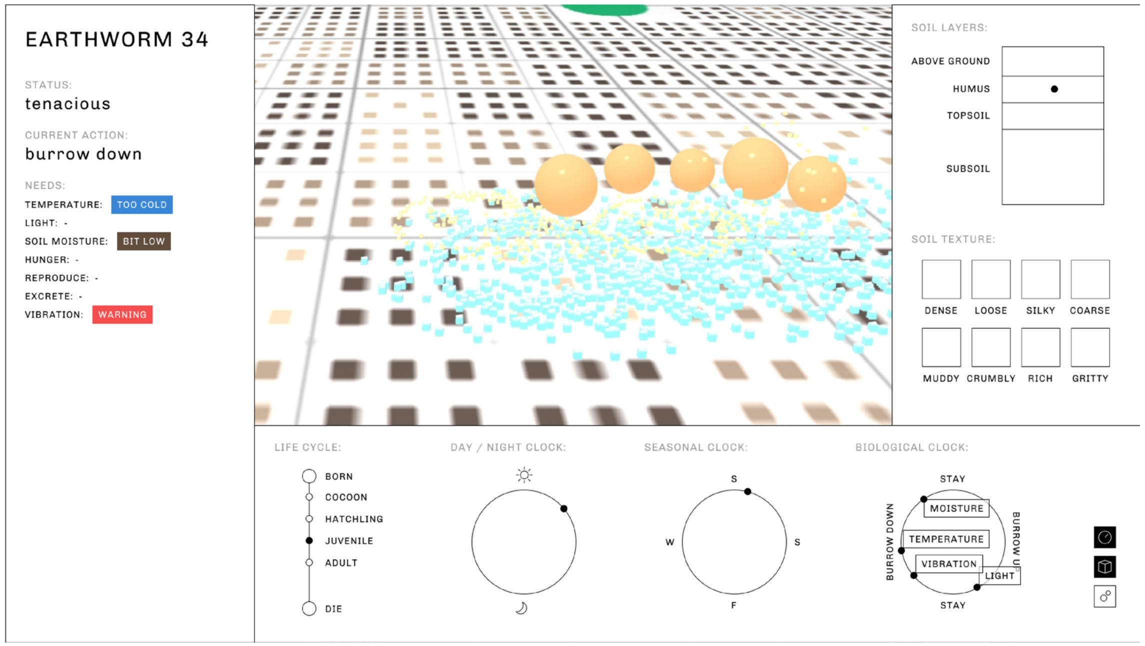
The second prototype focused on visually associating the data points with data creatures and detailing the pages showing each agent's activities and own time and space scale.



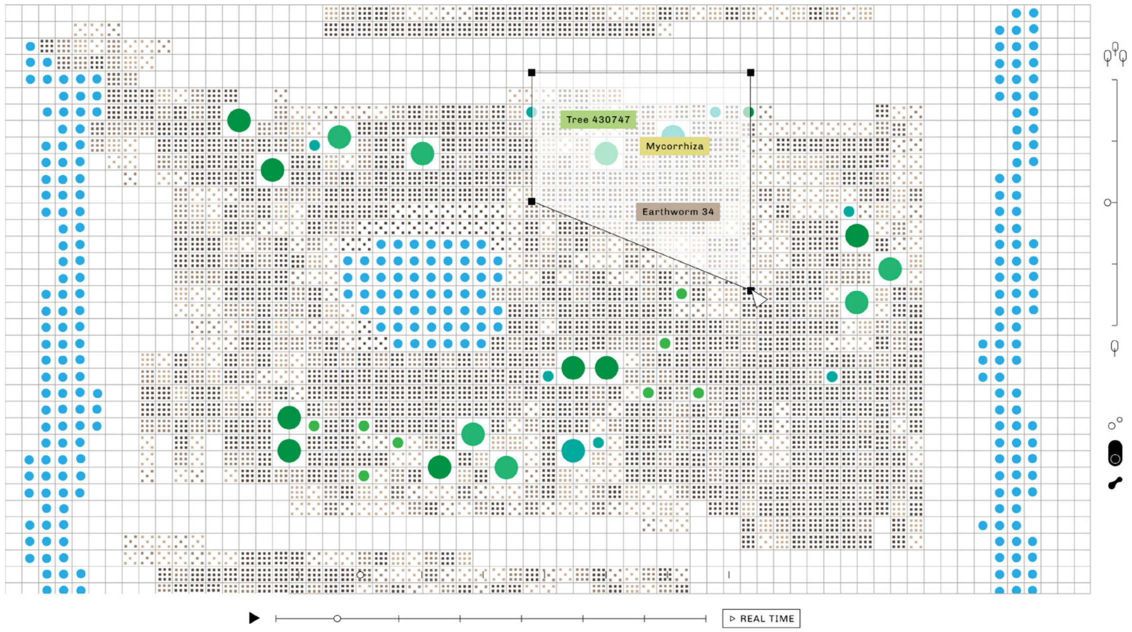
On the main page, the label of each agent leads to a page where the agent's activities are shown at the micro scale. On the left sidebar, the information about the agent, such as ID, status, current action, and needs (based on the variables) are displayed. Users can navigate time, space, and agency through the toggle buttons on the right bottom. When the button is toggled, the display shows information related to each scale in respective panels.



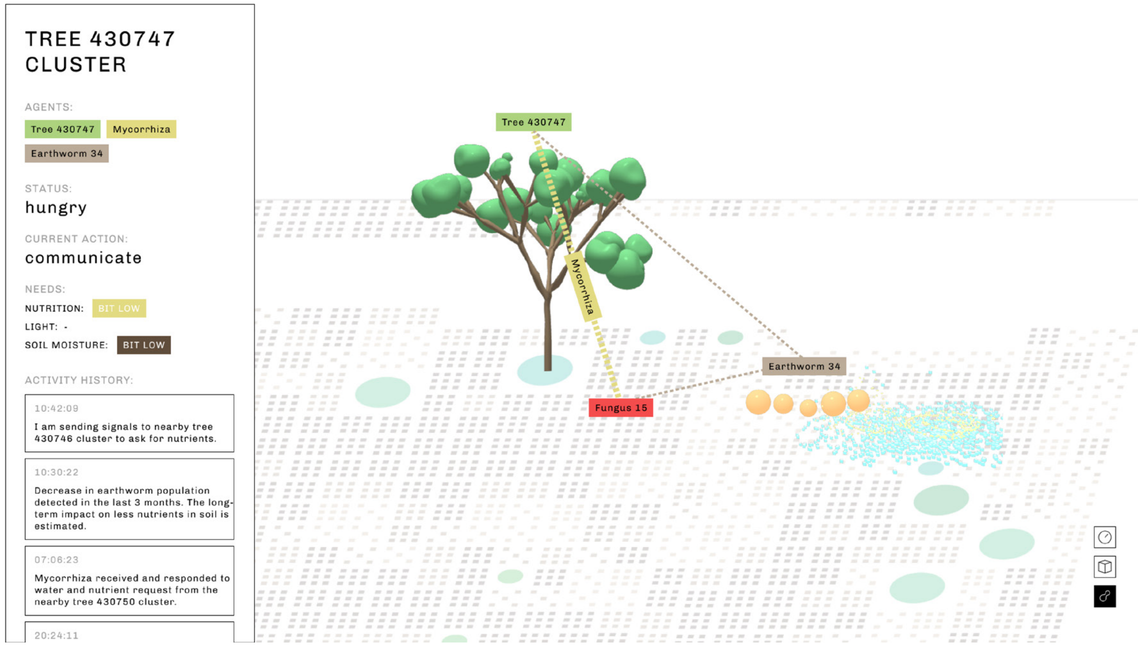
For instance, the time panel consists of multiple clocks that the agent possesses. In the image, you can see that the temporality of an earthworm is represented as four clocks.



On the space panel, in the case of an earthworm, the spatiality is described through soil layers and texture.



When the entanglement mode is toggled on the main screen, users can draw the boundaries of the section where they want to know more about.



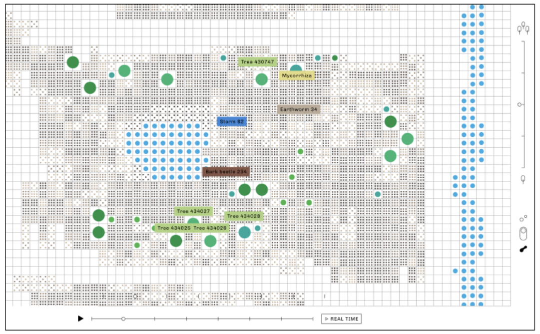
For example, the image above shows the cluster where trees, fungi, and earthworms are seen as a single organism. The navigation of time, space, and agency works in the same way as in the entity mode.

While the second version had improved visual consistency between data points and data creatures, one user pointed out that entanglements can only be made based on spatial proximity since the main screen shows the spatial composition of the forest from the top view. Therefore, relations that are made across time or based on temporal rhythms cannot be accessed through the current main screen.

PROTOTYPE 3

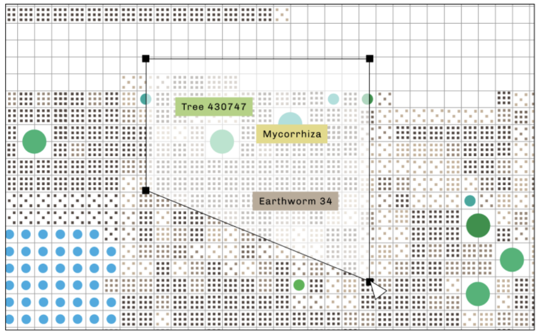
Building on the second prototype, the last prototype focused on developing features that manifest more-than-human concepts, such as agential cut and trans-corporeality.

MACRO VIEW

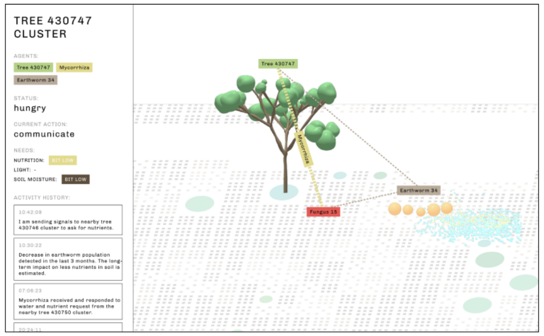


The user can observe the simulation result at the macro scale. This helps the user notice changes that manifest on large scales, such as population dynamics, migration, or succession.

MESO VIEW

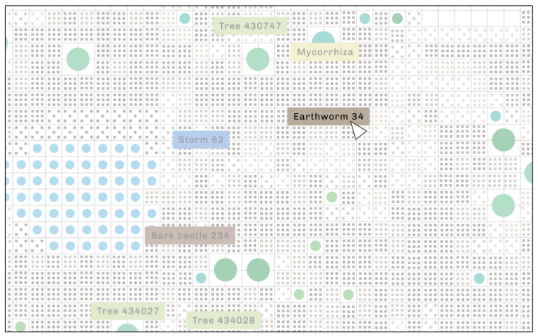


The user can draw the polygon to group entities. This grouped cluster is seen as a living community where each exists in balance and performs its own roles to sustain the survival of the community.

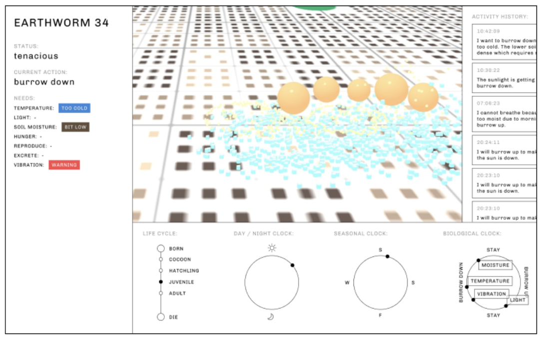


The user can observe the simulation result at the meso scale. This means that the future scenario is curated based on the situation and interest of the group: for example, what comes as a threat or benefit to the group. The dash and weight of the links illustrate the balance within the cluster

MICRO VIEW

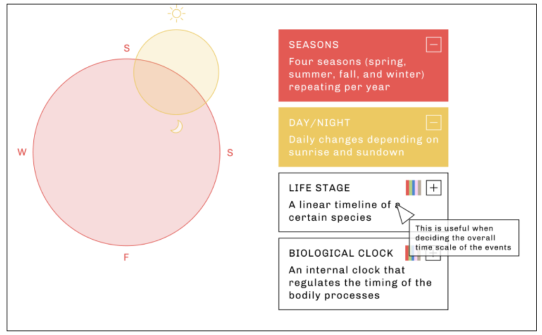


Each entity is labeled on the map. When clicked, it shows detailed information about the entity.

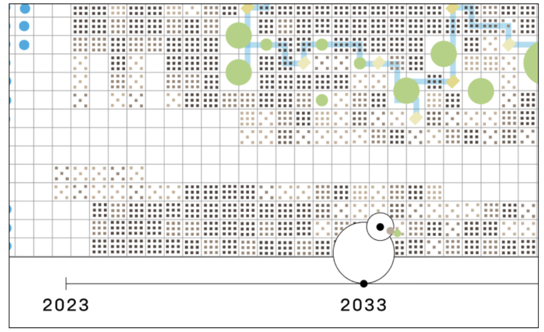


The micro view shows the information of a single species including its status, current action, needs, diverse clocks, spatiality, and activity history. In the main panel in the middle, real-time animation of the entity sprinkling data points is shown to explain the relation between the data points and its behaviors.

CYCLICAL TIMELINES

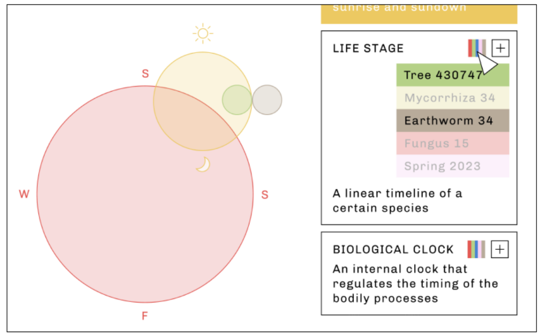


The user can design a timeline to curate the simulation results. Diverse seasonal rhythms or biological clocks can be selected and added.

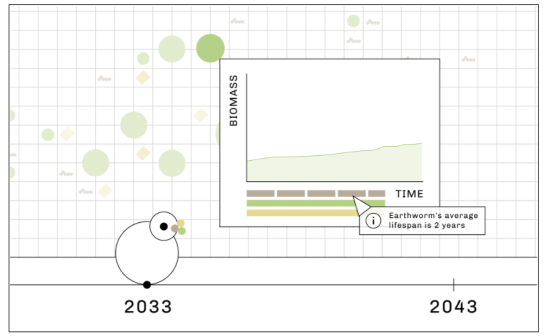


The customized timeline is shown as an icon in the time bar at the bottom of the macro view.

MULTISPECIES TIMELINE

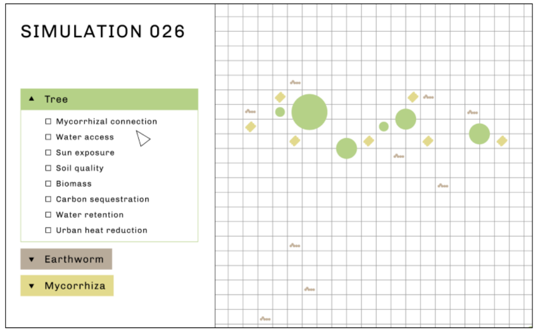


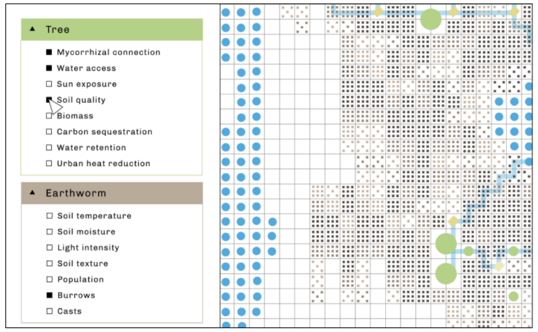
By selecting multiple species, the user can create a timeline consisting of diverse biological clocks or life stages of respective species.



For example, instead of a numerical representation of time, the data is presented relative to the lifespan of each species. The colored bars on the time axis each represent the respective species' lifespan.

SELECT DATA

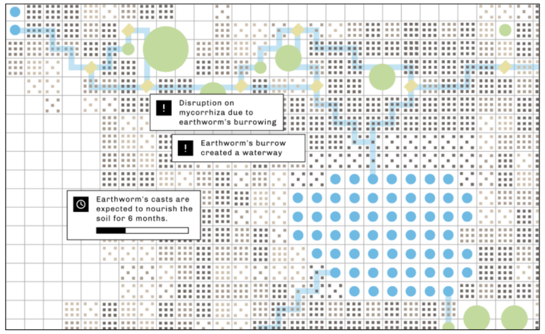




The user can select the types of information that they want to observe through simulations. The attributes of each agent are displayed in the drop-down menu.

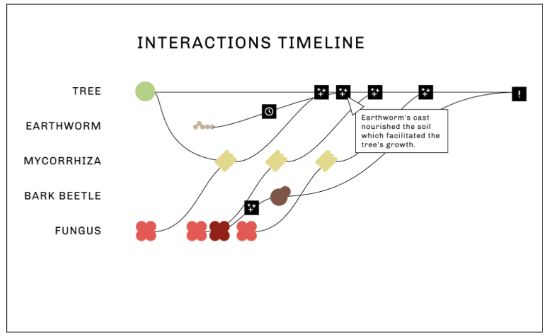
When multiple types of data are selected, they are shown in overlays.

INTERACTIONS MAPPING



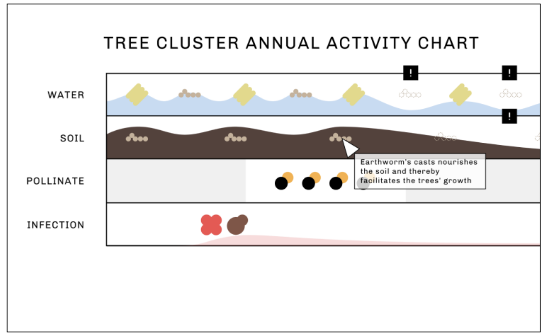
The events that arise from interactions are positioned on the map. The black box with each icon represent different types of events: for example, an exclamation mark signifying a warning, and a clock indicating the fixed-time impact.

INTERACTIONS TIMELINE



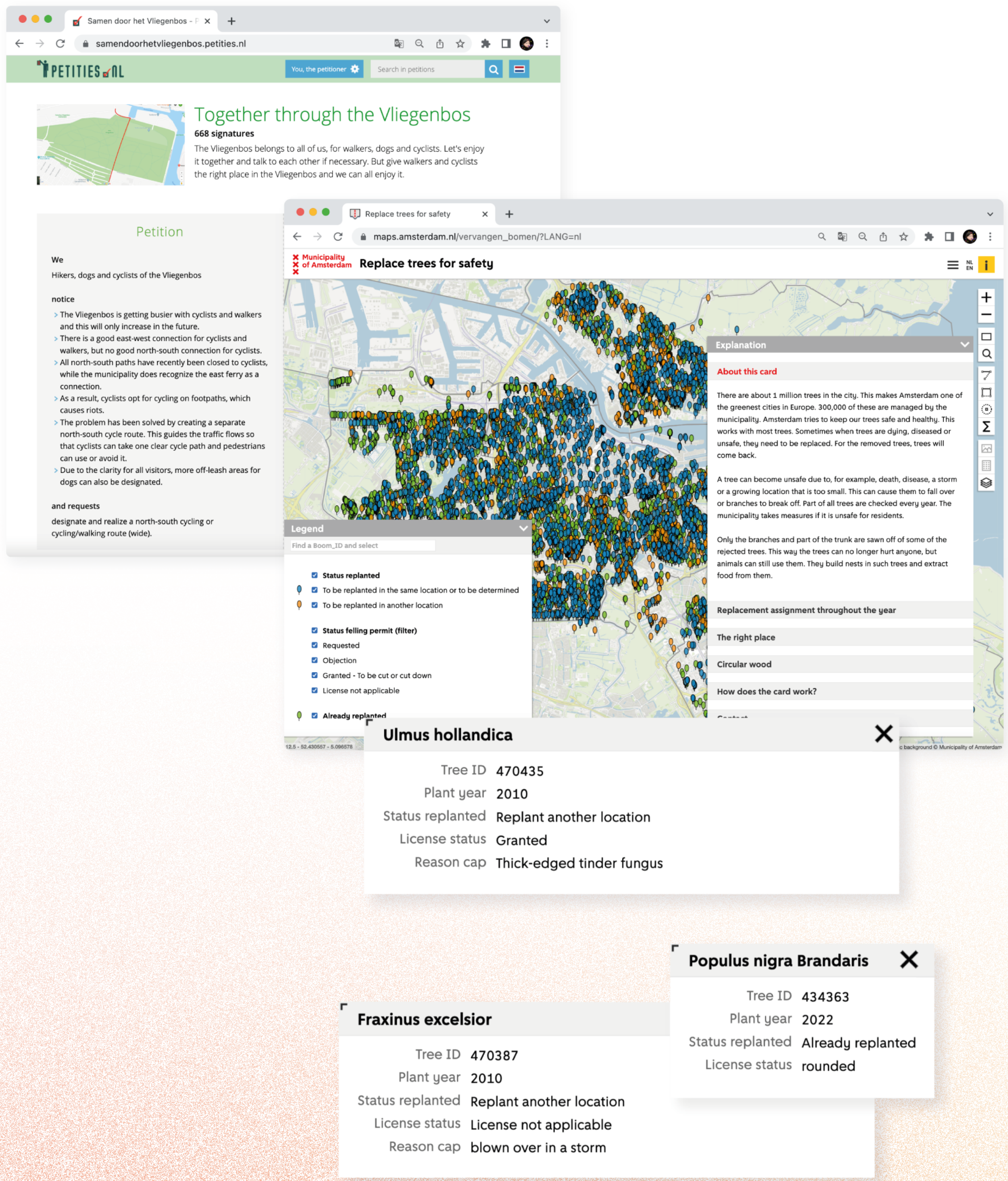
Interactions timeline highlights the interactions between two or more entities. The black box with each icon represents different types of events: for example, an exclamation mark signifying a warning, a clock indicating the fixed-time impact, and sparkles meaning mutually beneficial interactions.

CLUSTER ACTIVITY CHART



Cluster activity chart shows how its members contribute to the survival needs of the cluster. For example, the image above illustrates how different species are involved in providing water, nourishing soil, pollinating seeds, and infecting diseases.

EVALUATION: TOWARDS MORE-THAN-HUMAN FOREST GOVERNANCE



This chapter outlines how the interfaces designed in the previous chapter can be weaved as coherent experiences for supporting various forms of engagements in more-than-human forest governance. Three representative users of the simulation platform (i.e. a policymaker/urban planner, a citizen/civic activist, an agent-based model expert) were invited to evaluate the interface design, supposing that they would use them to achieve their own goals. Below are detailed descriptions of the evaluation session including the rationale for choosing the method, setup process, and results.

METHOD SELECTION

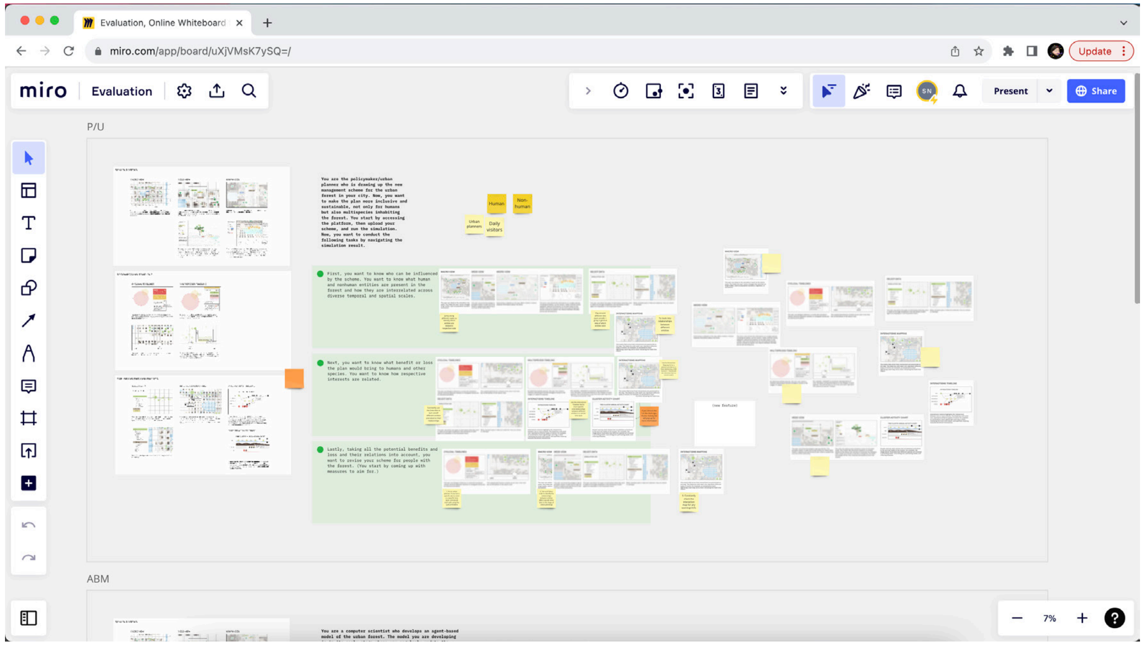
A scenario-based expert review was selected as an evaluation method to identify whether the designed features are helpful for respective users to access, understand, and act upon the forest data to achieve their goals. By observing how the participants make use of the features to complete tasks, I tried to identify which features are specialized for ascertaining a particular type of insight and what features are better when coupled together.

SETUP AND PROCESS

The three review sessions were conducted both offline and online, one-on-one. The participants each represented an urban planner, a citizen, and an agent-based model expert. The materials including the task scenarios and feature cards were provided on the Miro board, where the participants could freely arrange, annotate, or create the cards themselves. The scenario provided descriptions of the brief context (i.e. motivation for using the simulation platform and interests) and three tasks to achieve their goals. The order of the three tasks followed the steps from the more-than-human forest bodies workshop: 1) attuning, 2) situating, and 3) recomposing/negotiating. In order to get a clearer picture of their reactions and thought processes, the participants were asked to think aloud while reviewing the features based on the scenarios. The statements of the participants were documented along with their answers to pre and post-session interviews.

Below describes the process of the entire session after notices on the use of personal information and brief introductions on the context and design goal of this project.

1. Initially, during the pre-session interview, participants were asked to provide a brief introduction of their occupation and share their personal or professional engagement with urban forests or sustainability. Following that, they were prompted to contemplate any challenges they faced in those experiences.



2. Next, participants were shown the scenario and a set of cards explaining the features. It was noted that large parts of the features remained open-ended and thus they were free to specify, modify, or create features when needed.
3. For every task outlined in the scenario, participants were asked to choose the feature cards that they thought were pertinent for accomplishing the task. In cases where the rationale behind their choices was not provided, corresponding questions were given.
4. Finally, a semi-structured interview was conducted to delve deeper into the participants' experiences, impressions, and thoughts.

USE SCENARIO FOR A POLICYMAKER/URBAN PLANNER

SITUATION	TASK 1	TASK 2	TASK 3
You are the policymaker/urban planner who is drawing up the new management scheme for the urban forest in your city. Now, you want to make the plan more inclusive and sustainable, not only for humans but also multispecies inhabiting the forest. You start by accessing the platform, then upload your scheme, and run the simulation. Now, you want to conduct the following tasks by navigating the simulation result.	First, you want to know who can be influenced by the scheme. You want to know what human and nonhuman entities are present in the forest and how they are interrelated across diverse temporal and spatial scales.	Next, you want to know what benefit or loss the plan would bring to humans and other species. You want to know how respective interests are related.	Lastly, taking all the potential benefits and loss and their relations into account, you want to revise your scheme for people with the forest. (You start by coming up with measures to aim for.)

USE SCENARIO FOR A CITIZEN

SITUATION	TASK 1	TASK 2	TASK 3
You are the citizen who has lived several years next to the urban forest. As you visit the forest regularly, you started to wonder what could be the healthier future for both you and the forest. In order to learn what impact you and the forest can bring to each other, you decided to access the simulation platform and run the simulation. Now, you want to conduct the following tasks by navigating the simulation result.	First, you want to know what trees and other species inhabit the forest and how they would differently perceive and experience the forest.	Next, you want to know what how your daily activities or decisions from your city government would affect the forest.	Lastly, taking the mutual influences between you and the forest into account, you want to know whether the forest is healthy and what would be the healthier future for you with the forest.

USE SCENARIO FOR AN AGENT-BASED MODEL EXPERT

SITUATION	TASK 1	TASK 2	TASK 3
You are a computer scientist who develops an agent-based model of the urban forest. The model you are developing is in its early stage where you regularly update the model to help users of the platform (e.g. policymaker, urban planner, citizen) gain meaningful understanding and insights about the forest. In order to do so, you iteratively run the simulations, check whether there are emergent events or tightly connected relations among humans, trees, and other species, and reflect on how the model can better capture the forest. You have just set the parameters and ran the simulation. Now, you want to conduct the following tasks by navigating the simulation result.	First, you want to observe individual behaviors and emergent events arising from their interactions.	Second, you get to think about how your human users would interpret and act upon these event information. Then, you think about how those human interventions might influence multispecies inhabiting the forest.	Lastly, considering how simulation data, human users, and multispecies are interrelated, you want to revise your model for people with the forest. (You start by deciding what to elaborate or simplify in the model.)

EVALUATION CRITERIA

The data from the evaluation sessions was analyzed based on the four criteria mentioned below, which mirrors the approach taken in the more-than-human forest bodies workshop.
The collected data comprises 1) screenshots of the feature selections, 2) participants' comments and annotations during the testing, and 3) documentation of the interviews before and after the session. The qualitative data were first coded based on the four criteria to elucidate what information or modes of interactions with data each user prefers. These insights were then visualized in a diagram referring to their feature selections.

- Attuning: The user is able to notice the differences in temporality and spatiality of nonhuman species and attune to each species's body and relationship with the forest.
- Situating: The user is able to navigate the forest data through diverse temporal and spatial scales and speculate how the nonhuman actor would sense and react to a certain context.
- Recomposing: The user is able to create more-than-human bodies by recomposing his or her body with other bodies in the forest.
- Negotiating: The user is able to design or revise the interventions on behalf of the forest bodies while being aware of the trade-offs they are making.

RESULT

The original documentation of the participants' comments and interviews can be found in the Appendix. For ease of expression, the participant who was representing an urban planner was abbreviated into UP, a citizen being C, and an agent-based model expert being ABM.

ATTUNING

As all of the participants pointed out, Micro View was useful for getting to know the subjective worlds of individual species. In particular, while UP initially tended to prefer observing the events on macro scale and focus on data that has the highest numbers, in the post-session interview, she replied that she began to think about small creatures that have high impacts.

> UP: (...telling that she would start with Macro View...) I think Macro View is useful when observing which species is prominent. Like which species has the largest population or which has the largest size.
>
> Q: Is there a specific reason why you want to first observe data with the largest numerical figure?
>
> UP: It's just intuitive when grasping the overall data. Because there is a huge dataset.

(after the session)

> Q: What feature did you like the most and why?
>
> UP: I really liked Micro View. It constantly made me think about what those creatures would need and feel. It was also funny that an earthworm is taken as an example. It made me realize the impact of seemingly small creatures, for example, bees. Bees are very small but essential to the ecosystem. Likewise, an earthworm is tiny in its size but huge in its impact.
>
> UP: Also maybe because I, as an urban planner, am used to macro and meso scale. Information on the micro scale is very new, which nudges me to pay attention to different things and thus think differently.
>
> UP: And I also really like that the platform, although made by humans, shows scales that do not belong to humans.

ABM also added that he likes the way information on Micro View is not presented as conventional numerical figures but delivered based on the species' own temporality.

> ABM: I like Micro View in that their activities are not expressed in numbers in terms of ecosystem services for us but based on their life cycles. Like how they behave and interact with different species based on their own life cycles.

Overall, the participants mentioned that they would actively change timelines and scales to observe dynamic changes. They expected to discover new relations and interactions by playing around with different parameters and variables. In particular, C replied that Meso View would be suitable for finding out the relations.

> C: Let's suppose that I have succeeded in finding the tree that I liked. Then I will click on Meso View and see what other species are related to it. I might think, "I didn't know that there was this intricate relationship between a tree and an earthworm!"

SITUATING

Situating was the most tricky part where only C associated a personal context in a real forest with the forest data generated in the digital forest. Positing that he is attached to a particular tree that he wants to know more about, he requested a new feature that allows him to search specific trees on the platform.

> C: Given that I am a citizen who casually takes a walk in the forest, maybe I might have spotted a beautiful tree or even a tree that seems ill. Then I would want to search that tree. Then, I think I would need another feature that helps a user to search a certain tree. For example, when I hover over a certain species of tree, it shows a list of actual photos of the trees of that species in the forest. And then when I find the tree that I spotted in the list, I can click and it directs me to detailed information of the tree, such as the age or health of the tree. In this scenario, I think I will first start by observing the Micro View and later expand to the broader scales. Let's suppose that I have succeeded in finding the tree that I liked. Then I will click on Meso View and see what other species are related to it. I might think, "I didn't know that there was this intricate relationship between a tree and an earthworm!"

The reason why only C succeeded in situating the forest data might be accounted for by the lack of personal experiences in or with the forest, as UP and ABM often take the forest as an object to research for their occupation.

RECOMPOSING

While all of the participants were highly intrigued by data curated based on time, space, and agency beyond that of humans, C was the one who clearly expressed concerns on behalf of a tree, or even himself with a tree. However, it should be noted that C has already mentioned in the pre-session interview that he identifies himself as almost entangled with the tree throughout the years of field studies and tree planting activities.

> C: But maybe instead of knowing the biological or environmental attribute, I think, as a citizen, I would want to know more about when the latest treatment was given to this tree, showing for example when was the latest pruning, who did it, and if a problem occurred, how can someone intervene. Also, I want to know whether the tree that I like will still survive well in the future. Maybe in an extreme case, let's suppose that the tree that I liked dies 20 years from now. Then I will try to deduce the reason why it died, or even who is responsible for this death, in Meso View, observing the tree cluster.

NEGOTIATING

In terms of negotiating decisions on the forest, there was a clear difference between C who was actively involved in attuning, situating, and recomposing, UP who attuned to an earthworm and ABM who only noticed the differences with nonhuman species. For the last task, the participants were asked to imagine if they were taking action in their domains. For example, for C, reflecting on a healthier future for him with the forest, for UP, revising the plan for citizens with the forest, and for ABM, updating the computational model for people with the forest data. On one hand, C actively wanted to know what impacts a certain political decision would have on him with the forest, particularly the tree he was attached to, and urged channels for making further actions.

> C: In both cases, if I am dissatisfied with the current policy, I would want another feature to compare multiple scenarios and their impacts. And I want to know what decisions should be made at a specific moment.

And when certain political decisions are made in the forest, I would want to know what is the reasoning behind such decisions. For example, the replacement decision on the tree that I like, the replacement decision on the trees that surround the tree that I like, or the decision to build a new cycling route near the tree that I like. I would want to know what impact that political decision would bring and think about whether the decision sounds desirable or not.

When UP was asked to devise concrete measures for assessing the desirability of the plan, she used the "self-sustainability" stressing the coexistence and self-reliance on maintaining its own survival.

Q: If you were to come up with alternative development measures for people with the forest, what would they be?

UP: What comes to my mind now is self-sustainability. Sustainability to humans and nonhumans would be different, you know. We believe that nature should be constantly managed by human interventions but most of them are rather regarded as interferences to multispecies. I think I would choose measures that help improve the coexistence or maintain its own survival.

When ABM was how he would model differently after using the platform, he still tended to distinguish humans from nonhumans, suggesting the feature of showing the conflicting interests among humans and nonhuman species.

REFLECTION

From the evaluation, I was able to ascertain the following points of improvement.

1. Micro View and subjective curation of the data from the perspective of each species facilitates the process of attuning. A large set of data generated by simulation attracted users in that such data is not available from conventional technologies such as remote sensing.
2. For situating, there should be features that link the digital forest and the actual forest in reality such as a search function that shows the actual image of the forest. It is important to close the distance to the real forest by helping users associate forest data with their bodily experiences.
3. In order to open up one's border for recomposing, the interactions with more-than-human data should be seamlessly incorporated into everyday life, so that one's bodily experiences in the forest urge the need to access the platform and vice versa.
4. Negotiation on behalf of more-than-human forest bodies necessitates prior steps of attuning, situating, and recomposing.

Furthermore, there are remaining points of discussion which need further exploration.

- Whether to delivering data that we "think" we should know or what we are not interested in but might actually need to know

The author and UP discussed setting the timeline that the plan is aiming for. While UP first thought she would only look into the period that the plan aims to intervene in, she acknowledged the need to look beyond the designated timespan as they are often confined to human timescales.

UP: Again, I would first set the Timeline. For example, if I say that I am devising a city vision for Amsterdam in 2040, I will fix the time to 2040. And then jump back and forth between the Macro View and Meso View.

Q: You said that when you are drawing up a plan for a specific period, then you would fix the timeline of your interest and only focus on that. But given that this timespan often falls under our human timescale, wouldn't this human timespan rather hinder the urban planners from seeing their impact on the longer lifespan of certain species such as trees?

UP: Totally agree, that is one of the main problems of urban planning; that we are confined to the human scale. In that sense, I think just forcing people to see data that they "think" they might not be interested in could be interesting. For example, even if you set the timespan to 2040, the simulation still shows the future till 2100.

- Whether to include the human data or not

In the session, both UP and C asked why there is no data about humans. UP mentioned that overlaying human data with more-than-human data might lead to discovering new relations.

> UP: Maybe information about humans. Because more-than-human is still related to humans, right? If there is demographic information on the surrounding neighborhoods, for example, I wonder how their daily activities in the forest would be affected by agencies of the multispecies. Or whether their willingness to use the space changes? If the plants with poison become a threat to human users or the unruly growth of the bush discomforts the pedestrians, I think people would be unwilling to "use" the forest. Warning signs, for me, seem to focus on the survival of the multispecies or biodiversity for ecological reasons.
>
> UP: I also wonder what would happen when this is coupled with other types of datasets in smart cities such as air pollution, noise pollution, or building heights. For example, how high rises in Manhattan would be affected by the sun path or affect the sun exposure to the forest. And also how air or noise pollution from human activities would affect multispecies in the forest and vice versa.

However, C also raised concern about our tendency to favor human data since they are directly related to our interests.

> C: I wonder why there are no humans in the simulation. Is it intended? I also thought maybe it would be good to show quantified ecosystem services in the future and translate that into financial benefits. But maybe that is against the purpose of the platform since ecosystem services are what we, humans, value.

- Whether ABM is a prospective user of the platform or not

When asked whether they would actually use this platform for revising the model, ABM replied that the current design seems to be suitable for people without expert knowledge of technology.

> Q: I initially included the computer scientists who would develop the model as a potential user of the simulation platform but do you feel like visualizations within Jupyter or numerical data would be better for you to reflect on better capturing the realities?
>
> ABM: For a computer scientist or a system designer like myself, I think the design here focuses more on providing user-friendly visualizations. In the Python environment, we often use XML files or diagrams between data points generated by AI, and they might be easier for us for development purposes. So I think these intuitive and easy-to-understand designs are better for less techy people. There could be a gap between them and experts like programmers and urban planners.

CONCLUSION

In smart forests, forest data forms the backbone of forest governance by helping policymakers, urban planners, and stakeholders make informed decisions. Given the urgency of the climate crisis and the sixth extinction, I set out to lay the groundwork for more-than-human forest governance. This thesis documents my journey of exploring alternative ways to make sense of and act upon forest data.

Above all, I started with investigating the anthropocentric biases in the current forest data and examined the digital technology that produces these data, which was in this case, the digital twin simulation.

Taking one step back and questioning the onto-epistemology of this simulation technology, I conducted methodological experiments to figure out how I, as a design researcher, could approach forest data in a way that is inclusive and respectful of the interdependencies among trees, humans, and other species. This process necessitated decentering myself as a human researcher.

After iterative experiments and reflections, I conceptualized the body as a more-than-human lens to collect and make sense of forest data. By deconstructing and recomposing our own bodies in connection with the forest, this approach provided embodied, experiential, and performative metaphors. Through the workshop using these metaphors, the five more-than-human aspects of the forest data were discovered and later validated through discussions with computer scientists and ecologists.

Taking one step further to make the data actionable, I utilized the more-than-human bodies as a strong concept to design interactions with the forest data. In designing the interfaces, I focused on enabling seamless navigation in data across diverse temporal, spatial, and agential scales. Finally, through the evaluation sessions, I proposed recommendations and points of discussion for future research.

This thesis contributes to the interaction design and HCI communities, in particular more-than-human design and posthumanist HCI, by bridging posthumanist theories with decentering methodologies, strong concepts, and interface designs, all geared towards more-than-human forest governance. In an age brimming with pervasive digital technologies and pressing environmental challenges, this thesis opens up many starting points to reshape our relationships with data, trees, multispecies, forests, and perhaps ourselves.

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APPENDIX

DOCUMENTATION OF SCIENTIFIC DISCUSSIONS

DISCUSSIONS WITH COMPUTER SCIENTISTS

During the discussions with computer scientists, the main focus revolved around the feasibility of incorporating these themes into modeling practices and, if possible, how.

- Cyclical temporality: In ABM, cyclical temporality can be incorporated by modeling agents with attributes and behaviors that align with recurring cycles and rhythms. For example, agents representing trees can be programmed to go through life cycles, including stages such as seed germination, growth, reproduction, and eventually death. Additionally, agents can be programmed to respond to seasonal variations by adjusting their behaviors, such as shedding leaves in autumn or blooming in spring.
- Heritage and trajectory: ABM can capture the concept of heritage and trajectory by including mechanisms for accumulating and transferring information or characteristics across generations of agents. Agents can inherit attributes, behaviors, or states from their predecessors, representing the passing down of traits or knowledge. Additionally, the historical events and experiences of agents can be programmed to influence their future behaviors and interactions, creating unique trajectories within the simulation.
- Diverging boundaries: ABM can represent blurred boundaries of complex spatial and agential relationships. Agents can be programmed to interact and exchange information across different scales and spatial boundaries. For instance, agents representing trees can communicate and share resources through mycorrhizal networks, which may extend beyond the immediate forest boundaries. ABM can also account for emerging phenomena, such as spring or Dutch elm disease, by modeling individual agents' behaviors and interactions within the forest ecosystem.
- Balance and turbulence: ABM can capture the give-and-take dynamics and situational arrangements within the forest ecosystem. Agents can be programmed to engage in resource competition, cooperation, or conflict, resulting in temporary or long-term associations to maintain the balance. On the other hand, disturbances, such as insect infestations or natural disasters, disrupt the balance but generate new opportunities to restructure the forest or make adaptations to new conditions.
- Adaptation: ABM can incorporate the concept of adaptation by allowing agents to adjust their behaviors and characteristics based on the interactions and feedback received from other agents and their environment. Agents can be programmed with adaptive mechanisms, such as learning algorithms or decision rules, that enable them to respond and modify their behaviors in response to changing circumstances and the signals received from other agents.

DISCUSSIONS WITH ECOLOGISTS

From the conversations with ecologists, the five themes could be further related to ecological concepts.

- Cyclical temporality: Ecological concepts such as life cycles, phenology (seasonal timing of biological events), and trophic interactions are relevant. These concepts describe the recurring patterns and rhythms in the life cycles of organisms, the timing of ecological events in relation to seasons, and the interactions between different trophic levels within an ecosystem.
- Heritage and trajectory: Ecological concepts like succession, genetic inheritance, and evolutionary processes are relevant. Succession describes the sequential changes in the composition and structure of communities over time. Genetic inheritance influences the transmission of traits from one generation to the next, while evolutionary processes shape the trajectories of species and their adaptations over longer time scales.
- Diverging boundaries: Ecological concepts such as ecosystem connectivity, landscape ecology, and species interactions are relevant. Ecosystem connectivity refers to the interconnectedness of habitats and the movement of organisms across spatial boundaries. Landscape ecology explores the spatial arrangement and distribution of different ecosystems and their components. Species interactions, including mutualism, predation, and competition, can transcend traditional boundaries and shape the dynamics of ecosystems.
- Balance and turbulence: Ecological concepts like ecological balance, ecological resilience, and disturbance regimes are relevant. Ecological balance refers to the state of equilibrium in ecosystems, where the interactions between components are relatively stable. Ecological resilience describes the capacity of ecosystems to withstand disturbances and retain their basic structure and functions. Disturbance regimes encompass the natural or human-induced disturbances that shape the dynamics and structure of ecosystems.
- Adaptation: Ecological concepts such as niche differentiation, coevolution, and ecological plasticity are relevant. Niche differentiation describes the process where species evolve to occupy different ecological niches to reduce competition. Coevolution refers to the reciprocal evolutionary changes in interacting species. Ecological

plasticity refers to the ability of organisms to adjust their traits and behaviors in response to environmental changes or interactions with other organisms.

INTERVIEW SCRIPT

[Welcoming and appreciation]

Thank you for participating in this evaluation session.

[Notice on the use of the personal information and data]

Before we start, I want to first let you know what kinds of personal information and data will be collected and how they will be processed. In this session, any personal information other than your occupation will be anonymized. The outcomes of the session will be used only for the research purpose which does not involve any commercial interests. Finally, if you would like to be informed later on how your data has been processed, feel free to reach out afterward. Do you have any questions or doubts?

[Introduction to the project]

[Pre-session Questions]

- Can you describe your occupation and domain of expertise?
- What projects, studies, or works have you done in relation to urban forest (or sustainability)?
- What were the difficulties that you have encountered in those experiences?

[Walk through the scenario and the feature cards]

[Session]

[Post-session questions]

- What feature did you like the most and why?
- Are there any improvements you want to make? Or new features?
- What do you think this platform is different from the conventional data visualizations?
- Are there any other cases that you want to utilize this platform for?
- Are there any final remarks?

DOCUMENTATION OF EVALUATION SESSIONS

URBAN PLANNER

[Pre-session Questions]

Q: Can you describe your occupation and domain of expertise?

UP: I have studied architecture and urbanism for my undergraduate studies which partly span building sciences.

My current personal interests revolve around using geometrics for sustainability. For example, using big data and spatial engineering for social or environmental sustainability.

Q: What projects, studies, or works have you done in relation to urban forest (or sustainability)?

UP: I have taken a few urban planning courses and done development case studies and design projects regarding urban issues. There, I have written a research paper about how urban greenery facilitates social cohesion.

I was also a part of the architecture student team building sustainable solar houses and have experience working as a sustainability researcher for a biodiversity project in Germany.

Q: What were the difficulties that you have encountered in those experiences?

UP: In urban planning, sometimes you find yourself using sugar-coated terms for building the vision but actually having trouble translating them into concrete actions. In relation to that, I want to know more about what specific measures should be taken to enhance biodiversity in cities by delving into their internal mechanisms.

[First task]

UP: First, I think I would jump back and forth between diverse scales (i.e. Macro View, Meso View, Micro View) and play around with the dataset using Select Data.

UP: I think the Macro View is useful when observing which species is prominent. Like which species has the largest population or which has the largest size.

Q: Is there a specific reason why you want to first observe data with the largest numerical figure?

UP: It’s just intuitive when grasping the overall data. Because there is a huge dataset.

UP: I think I would use Meso View to zoom into the section that I am interested in and to understand the relationships within there. Like which interactions are out there and how active they are.

Q: What sections would you be interested in?

UP: Where the most entities are congregated in Macro View or where the most warnings are (in Interaction Mapping).

UP: Then in Micro View, I would want to know the respective roles and needs of each species. And I would toggle on and off data points with Select Data and play with it to find some correlations.

[Second task]

UP: For this task, I would start to observe the timeline, to see how human interventions affect the ecosystem over time. In that sense, I think Interaction Mapping would be really useful. Again, toggle on and off the data points and play around the timeline. I really like that as I move the timeline the changes will be shown in real-time.

UP: So I think I would first play around with Select Data and when I spot some interesting correlations, Design Timeline in accordance with that and observe Interaction Timeline in detail.

Q: When would you use Interaction Mapping and when would you use Interaction Timeline?

UP: I think Interaction Mapping would be more useful when delving into events happening around the fixed time point. And Interaction Timeline would be more useful when observing a series of events over a certain time period (what interactions happen and how each entity is related to one another)

Q: When would you use Cyclical Timeline and when would you use Species Timeline?

UP: I would use it together because a biological timeline of a certain species would be definitely affected by cyclical clocks. The way I would do that..., I would fix one variable and play around with other variables. For example, select a certain species and try changing seasonal clocks.

UP: Also when every information is presented on the screen altogether, it would be quite chaotic. I would put Select Data in the left panel, tinker with the timeline, and Interaction Mapping on the main center screen, and when the popup window is clicked, I want to be directed to the detailed data like Cluster Activity Chart.

[Third task]

UP: Again, I would first set the Timeline. Depending on the timespan of the plan, I will fix on a certain year. And then jump back and forth between the Macro View and Meso View. In this stage, I wouldn't necessarily use Micro View except when it is really needed. I think the information on Meso View would be enough to set the direction.

[Additional questions during the session]

Q: Isn't the freedom of scales too overwhelming to you? What would help you to be well-guided through numerous options?

UP: I think it would be quite clear when your goal is quite clear. For example, if I say that I am devising a city vision for Amsterdam in 2040, then the timespan is set which reduces many variables.

The information hierarchy would be most important. For example, I would use the Cluster Activity Chart at the latest because it shows the most specific kinds of information. In terms of urban planning, we tend to think on a macro scale. Information on a micro scale would be more useful for ecologists who research biodiversity.

Q: You said that when you are drawing up a plan for a specific period, then you would fix the timeline of your interest and only focus on that. But given that this timespan often falls under our human timescale, wouldn't this human timespan rather hinder the urban planners from seeing their impact on the longer lifespan of certain species such as trees?

UP: Totally agree, that is one of the main problems of urban planning; that we are confined to the human scale. In that sense, I think just forcing people to see data that they "think" they might not be interested in could be interesting. For example, even if you set the timespan to 2040, the simulation still shows the future till 2100.

Q: Since you liked the Interaction Mapping feature, what would you like to observe more in Interaction Mapping other than warnings?

UP: Maybe information about humans. Because more-than-human is still related to humans, right? If there is demographic information on the surrounding neighborhoods, for example, I wonder how their daily activities in the forest would be affected by agencies of the multispecies. Or whether their willingness to use the space changes? If the plants with poison become a threat to human users or the unruly growth of the bush discomforts the pedestrians, I think people would be unwilling to "use" the forest. Warning signs, for me, seem to focus on the survival of the multispecies or biodiversity for ecological reasons.

Q: If you were to come up with alternative development measures for people with the forest, what would they be?

UP: What comes to my mind now is self-sustainability. Sustainability to humans and nonhumans would be different, you know. We believe that nature should be constantly managed by human interventions but most of them are rather regarded as interferences to multispecies. I think I would choose measures that help improve the coexistence or maintain its own survival.

[Post-session Questions]

Q: What feature did you like the most and why?

UP: I really liked Micro View. It constantly made me think about what those creatures would need and feel. It was also funny that an earthworm is taken as an example. It made me realize the impact of seemingly small creatures, for example, bees. Bees are very small but essential to the ecosystem. Likewise, an earthworm is tiny in its size but huge in its impact.

Also maybe because I, as an urban planner, am used to macro and meso scale. Information on the micro scale is very new, which nudges me to pay attention to different things and thus think differently.

Q: Are there any improvements you want to make? Or new features?

UP: Maybe it is already implemented in the design but I think it would be really cool if you could model and visualize climate change in the simulation. For example, like shows that the spring of 2033 is different from that of 2043.

Q: What do you think this platform is different from the conventional data visualizations?

UP: Definitely a huge number of variables and a vast amount of datasets that are visualized in real-time, also showing their interactions.

Q: Are there any other cases that you want to utilize this platform for?

UP: I think of course this would be really useful for urban planners and maybe also for ecologists when they are researching biodiversity.

And maybe for students as well, for educational purposes. I think it will intrigue their interests in multispecies and later they might choose to consider multispecies in their studies.

I also wonder what would happen when this is coupled with other types of datasets in smart cities such as air pollution, noise pollution, or building heights. For example, how high rises in Manhattan would be affected by the sun path or affect the sun exposure to the forest. And also how air or noise pollution from human activities would affect multispecies in the forest and vice versa.

Q: Are there any final remarks?

UP: I really liked it. If this platform can show changing multi-relations in real-time, I think it would be very useful in urban planning.

And I also really like that the platform, although made by humans, shows scales that do not belong to humans.

Also, the aesthetics were overall very pleasing and the diagrams were easy to understand.

Another thought that comes across into my mind is that maybe the simulation can be used to arouse awareness but also it might be used for uplifting people in that it enables people to dream till 2300 for example. I often feel very pessimistic about the future of humanity. I am not sure if humanity will manage to survive till 2100. But if you can simulate and thereby get to imagine the future by 2300, I think it might help people have more optimistic attitudes when engaging with the future.

CITIZEN

[First task]

C: I think I will first try out all the features to spot something interesting. I don't think that the sequence of the features would matter at this stage.

But I think many people including myself would first choose to see Macro View, as if they first see the Google Map. Think I can find some interesting areas by observing the entire region. Like when I am bored and thinking, "Hmm, let's see what our neighborhood forest would look like," I access the platform, starting with the Macro View, spot some interesting areas, and narrowing down to the Meso View or Micro View. For example, suppose that I was particularly intrigued by the relationship between an earthworm and a tree in Meso View. Then I think I will try drawing polygons in areas where there are a lot of earthworms or very few of them. I will probably start to wonder why. Then I will use Cyclical Timelines to see in which season earthworms appear the most or least and check whether their population is decreasing or increasing in a broader time scale. I would then want another feature to find out the spikes in the earthworm population. For example, the time stamp that earthworm population has significantly decreased. I would probably wonder why earthworms have vanished and whether it is my responsibility or not.

C: Or given that I am a citizen who casually takes a walk in the forest, maybe I might have spotted a beautiful tree or even a tree that seems ill. Then I would want to search that tree. Then, I think I would need another feature that helps a user to search a certain tree. For example, when I hover over a certain species of tree, it shows a list of actual photos of the trees of that species in the forest. And then when I find the tree that I spotted in the list, I can click and it directs me to detailed information of the tree, such as the age or health of the tree. In this scenario, I think I will first start by observing the Micro View and later expand to the broader scales. Let's suppose that I have succeeded in finding the tree that I liked. Then I will click on Meso View and see what other species are related to it. I might think, "I didn't know that there was this intricate relationship between a tree and an earthworm!" Then I think I would use the Select Data feature to find out what environmental or human factors are involved in that tree. But maybe instead of showing the biological or environmental attribute, I think, as a citizen, I would want to know more about when the latest treatment was given to this tree, showing for example when was the latest pruning, who did it, and if a problem occurred, how can someone intervene. Also, I want to know whether the tree that I like will still survive well in the future. Maybe in an extreme case, let's suppose that the tree that I liked dies 20 years from now. Then I will try to deduce the reason why it died, or even who is responsible for this death, in Meso View, observing the tree cluster. I think Interaction Mapping would show a series of events space-wise and Interaction Timelines would show them time-wise. I would try to discover how this death happened, what kinds of interactions contributed to it, and how this death overall would affect the entire ecosystem like a detective.

[Second task]

C: Maybe in a similar vein to the first task, I think the approach would differ whether I am interested in the greenery in general or attached to a specific tree. But in both cases, I would start with Macro View as I am familiar with seeing Google Maps.

C: For example, if I am a citizen who is interested in accessibility to green space, then I would probably be interested in the surface area of the green. Then when I simulated the urban policy and the results indicate that the green area in our neighborhood is decreasing or the health of the tree population in general is worsened, then I would focus on observing the changes in Macro View.

C: On the other hand, if I am a citizen who is personally attached to a single tree, then I would be interested in the future health of the tree based on the current policy. And because I already know where the tree is, I will fix the location of the tree, and observe the vitality of the tree in Meso View. Interaction Mapping seems like a very powerful tool. But maybe I would want the impact to be shown as quantified. For instance, the material flow between Tree A and Tree B has decreased from 100% to 30%.

In both cases, if I am dissatisfied with the current policy, I would want another feature to compare multiple scenarios and their impacts. And I want to know what decisions should be made at a specific moment.

[Third task]

C: As a citizen, I would also want to know what others think about what a healthy forest is. For example, what are the experts' definition of a healthy forest? What criteria would they use and what kinds of reasoning support that? And when certain political decisions are made in the forest, I would want to know what is the reasoning behind such decisions. For example, the replacement decision on the tree that I like, the replacement decision on the trees that surround the tree that I like, or the decision to build a new cycling route near the tree that I like. I would want to know what impact that political decision would bring and think about whether the decision sounds desirable or not. Furthermore, if those decisions can be archived, I would want to check the history to decide whether a current policy seems right or wrong. However, I don't know what actions can be taken after that.

C: As I said, Interaction Mapping seems like a powerful tool. I would compare the impacts of the different decisions using this feature.

C: I wonder why there are no humans in the simulation. Is it intended? I also thought maybe it would be good to show quantified ecosystem services in the future and translate that into financial benefits. But maybe that is against the purpose of the platform since ecosystem services are what we, humans, value.

C: So when thinking of measures for knowing the healthiness of the forest, I think maybe we can measure the number of links between entities and how strong those are. Maybe that might represent the vitality of the forest.

[Pre-session Interview]

Q: I should have asked these prior to the question but can you describe your personal relationship or experience with the forest and domain of expertise? What projects, studies, or works have you done in relation to urban forest (or sustainability)?

C: I am a PhD student and my major is forestry and ecology. I was born and raised in cities so I used to idealize a forest. That became a core motivation to study and know more about the forest.

C: Luckily I had an opportunity to study Redwood Forest in California and I spent more than half of the time in the forest during my studies. I could see how diverse forms of life interrelate with each other and how the forest dynamically changes in relation to the forest fire.

C: Then when I started to study in Germany, I had an opportunity to take action together with citizens on the forests under stress due to climate change. By planting diverse species of trees, I learned a lot about how the forest can be rebuilt. Now, I almost identify the forest's interest with mine. The forest is no longer a distant object but a part of me.

Q: Were there any difficulties that you have encountered in those experiences?

C: First, there are difficulties in terms of understanding the forest. Indeed, forests are significantly complex and it is very easy to misunderstand them when you follow your instincts. If you rely too much on an academic approach when understanding them, you soon realize that there are more things that you don't know compared to what you think you know.

C: Also, when it comes to designing the interventions, we might conclude whether it is right (i.e. brings positive impact) theoretically, but in real life, you never know what ramifications it would bring. There is a constant dissatisfaction and fear sprouting from the fact that our understanding is inevitably imperfect. I keep thinking, "What if I do wrong? What if I cannot grasp the phenomena right?"

C: When it comes to implementing the actions after making decisions, you encounter difficulties dealing with the existing rules of society. Whether it is a single tree or a forest, there is a certain way that they have been managed. It is very hard to break that inertia and persuade people that a new approach is needed. I think in both Germany and South Korea, I had a lot of difficulties when getting consent and support from people.

Q: Maybe is that a reason why you wanted a feature that shows the impact of quantified measures?

C: Yes, maybe. In every project, there should be numeric measures that backbones why this project should be implemented. Also after the project has been implemented, the result should be evaluated in numeric measures.

[Post-session Questions]

Q: What features did you like the most and why?

C: In Macro View, you see diverse data that cannot be captured from remote sensing. I think these various layers of information have a huge potential. And there is a clear hierarchy between the information.

What I also liked is the timeline icon: this icon that a user can dial the circle and the other circles revolve accordingly like a solar system.

And I like that you use a unified visual language to help understand the complexity of a forest.

Q. Are there any improvements you want to make? Or new features?

C: I have never seen such a detailed model of the forest. And it is very visually pleasing. I like it very much that it seems to imply that forests and the problems that they currently have are so important that you need to look into them in detail.

Q: Is there any other case that you want to utilize this platform for?

C: I know that there are many organizations that are interested in specific species, like birdwatchers or berry foragers. Since this platform is focused on trees, you might make another version; like for birds. And you might be able to utilize their data as well to figure out. I think if you collect data one by one just like that, it will after all make a great database.

Q: As you might have already noticed, there is a lot of freedom in choosing granularity (like options to select variables). Wasn't it overwhelming to you? Do you need any guidance?

C: I understand that it might be overwhelming. Maybe you can provide a step-by-step tutorial or intentionally hide some features at the beginning and gradually release them as the user gets familiar with the platform.

Q: Are there any final remarks?

C: I think this idea is very ambitious, and I really hope this can actually be realized.

AGENT-BASED MODEL EXPERT

[Pre-session Questions]

Q: Can you briefly describe your occupation and domain of expertise?

ABM: I am a complex system scientist working on issues around climate change and human-centered and responsible use of AI.

Q: What projects, studies, or works have you done in relation to urban forest (or sustainability)?

ABM: We've been doing TreesAI, which is one of the main projects in relation to urban forests which goes back to 4 or 5 years ago.

Q: What were the difficulties that you have encountered in those experiences?

ABM: When it comes to sustainability and green spaces, there are several layers of difficulties. One is about questioning how you can use science in decision-making through hands-on products and another is creating new perspectives on how we understand and interact with nature.

[First task]

ABM: I will first start with Micro View to observe what each species does. I want to add information about interaction points with other actors there. And Interactions Timeline to see how different cycles of different species overlap in time and what interactions happen there. Any information about interactions in time and space would be valuable. Maybe for spatial interactions, I think Interaction Mapping would help. But I want more dynamic versions, not in still cuts. For example, a tree doesn't move around although tree sizes might change over time, but other species can move around. I want to see how different species move around and interact with each other. And within the fixed snapshot, I would play with dynamic timelines.

[Second task]

ABM: For this task, the essence would be to make cognitive changes in people. In that sense, I like Micro View in that their activities are not only expressed in numbers in terms of ecosystem services for us but also illustrate how each species has its own life cycle and how they are interacting with different species.

[Third Task]

ABM: For this, I think it would be nice to map the different actors and how their respective interests are conflicting.

Q: I initially included the computer scientists who would develop the model as a potential user of the simulation platform but do you feel like visualizations within Jupyter or numerical data would be better for you to reflect on better capturing the realities?

ABM: For a computer scientist or a system designer like myself, I think the design here focuses more on providing user-friendly visualizations. In the Python environment, we often use XML files or diagrams between data points generated by AI, and they might be easier for us for development purposes. So I think these intuitive and easy-to-understand designs are better for less techy people. There could be a gap between them and experts like programmers and urban planners.

[Post-session Questions]

Q: What features did you like the most and why?

ABM: I liked Micro View which shows the state of the agent, linear and cyclical clocks, and what actions they take in such cycles. Any elaboration on that would be interesting to me.

Q: Can you elaborate on what you mean by interactions in different cycles?

ABM: Let's say there is a worm and a tree. A tree would have a day/night clock and they would act differently depending on the clock. When there is plenty of sunlight in the daytime, they do photosynthesis and during the night, they will consume oxygen. And, I am saying this in pure imagination, maybe the products of photosynthesis might be food for the earthworm. Likewise, I am interested in how different clocks would interact with each other. This would maybe require more background domain knowledge.

Q: Is there any other case that you want to utilize this platform for?

ABM: Maybe as a dashboard for citizens. To change our perspectives and arouse awareness on biodiversity; that there are other important things other than ecosystem services.

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy". Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Nam 6468

initials: S given name: Seowoo

student number: 5546591

street & no.:

zipcode & city:

country:

phone:

email:

Your master programme (only select the options that apply to you):

IDE master(s): IPD ( ) DfI (★) SPD ( )

2nd non-IDE master:

individual programme: - - (give date of approval)

honours programme: Honours Programme Master

specialisation / annotation: Medisign / Tech. in Sustainable Design / Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: Elisa Giaccardi — dept. / section: HCD / HICD

** mentor: Iohanna Nicenboim — dept. / section: HCD / HICD

2nd mentor: Bulent Ozel

organisation: Lucidminds

city: Amsterdam — country: The Netherlands

comments (optional): While the supervisory team will give guidance on human information communication design and more-than-human design, Lucidminds (the client) will provide perspectives from computational social science.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Elisa Giaccardi date 02 - 03 - 2023 signature

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: 33 EC

Of which, taking the conditional requirements into account, can be part of the exam programme 30 EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

NO missing 1st year master courses are:

name Robin den Braber date 24 - 04 - 2023 signature Robin den Braber Digitaal ondertekend door Robin den Braber Datum: 2023.04.24 07:41:16 +02'00'

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: ★ APPROVED NOT APPROVED

Procedure: ★ APPROVED NOT APPROVED

comments

name Monique von Morgen date 02 - 05 - 2023 signature

More-than-Human Approach to Digital Twin Simulation for Urban Forests

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 02 - 03 - 2023

30 - 08 - 2023 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

[Context] Along with the worldwide adoption of smart cities, smart forests are gaining traction as technologies to manage and mitigate environmental change. By and through processes of digitalizing forests, urban forests are viewed and constructed as green infrastructures that provide diverse ecosystem services to people and the planet. The digital technologies and data practices that enable the digitalization of forests play a crucial role in shaping our notions of and relations with forests by differently sensing, valuing, and assessing forests processes (Gabrys, 2012). Research in this area is needed in order to further establish how these technologies both enable and constrain particular modes of governance and engagement with forests (Gabrys, 2020). Without this research, the development of smart environments such as smart forests runs the risk of producing social-political inequities and undemocratic governance, as has been identified with smart cities (Shelton et al., 2015; Zook, 2017).

[Stakeholders] In response to the climate crisis and calls for civic infrastructure, Lucidminds have designed Green Urban Scenarios framework (GUS) (see Figure 1), a digital twin representation and simulation of urban forests and their impact. This is powered by agent-based modeling which simulates urban forest's growth and their future ecosystem services under varying weather conditions, maintenance regimes, species compositions, spatial distributions, and exposures to diseases. Since Lucidminds aim for climate-resilient and socially just urban futures, they want to extend GUS by taking more-than-human considerations and explore its potential applications to their ongoing projects (i.e. TreesAI, CiFi). For example, adding nonhuman actors and their entangled interactions in the simulation can help people understand others' needs and make forests as more inclusive, resilient and versatile infrastructures in the long term. Moreover, making people attuned to trees and nonhumans species in forests can help nature-based solutions (NbS) project developers to be aware of the potential environmental impacts of their projects and draw more NbS investments.
On the other hand, the fields of design and HCI have encountered more-than-human turn with imperatives to tackle pressing environmental crisis and emerging technologies being highly entangled in our societies with their sensing and processing capabilities (Coskun et al., 2022). While discourses on developing and deploying more-than-human design methodologies have been vigorous in academia, there exist only a few cases where such methodologies are applied to industry projects. Hence, the project aims to bridge more-than-human discourses and practices of urban forest (and further civic assets) governance, providing an empirical case for design and HCI communities.

[Opportunities and Limitations] GUS creates diverse future scenarios of what can happen to and within the urban forest (see Figure 2) along with trajectories of how it happens. While the most common scenario can be used to predict what is likely to happen, the outliers can teach us what can happen alternatively. When nonhuman agents and their interactions are added to the simulation, such alternative future scenarios and their trajectories can be resources for designing new modes of governing and engaging with urban forests in more-than-human perspectives. Yet, since these future scenarios and the trajectories exist as numeric data, they need to be embodied so that people can communicate and interact with more-than-human urban futures.

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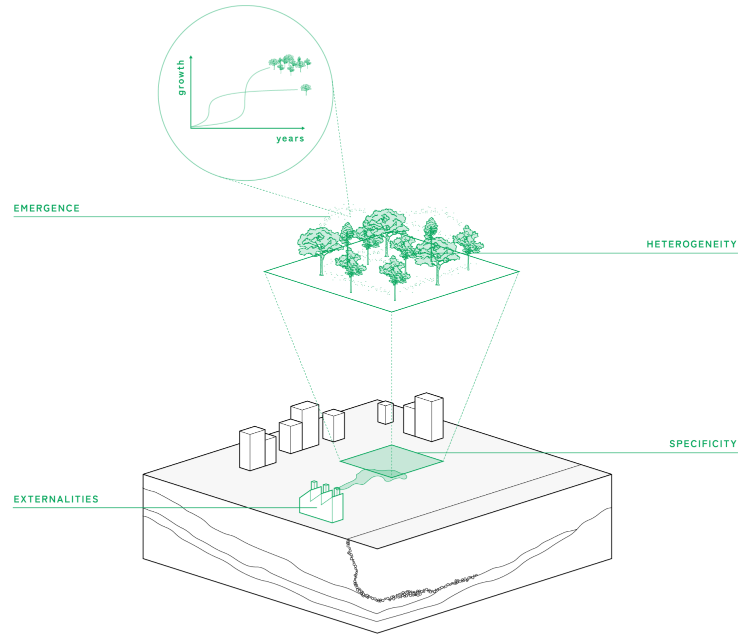


image / figure 1: Modeling features of GUS framework representing urban forest as a complex system

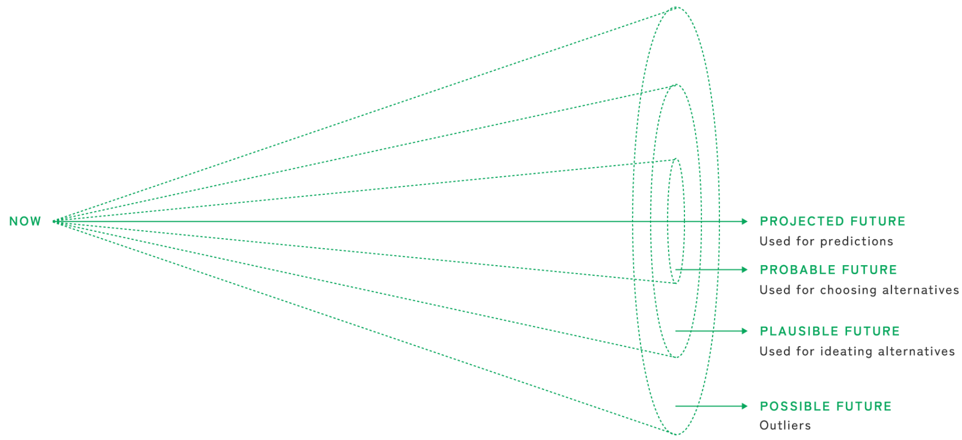


image / figure 2: Simulated Futures by GUS (Adapted from Voros (2003))

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Urban forests are complex systems where diverse human and nonhuman actors are intricately connected. However, urban politics and planning have yet to embrace the urban as a multispecies, multi-thing reality in which nonhumans are active participants alongside in shaping cities and places (Quinn, 2020). Given that smart urban forest approaches are largely utilized in urban forest policies to justify, enhance, and influence goals and actions (Prebble et al., 2021), further research is needed to examine how such digital technologies both enable and constrain particular modes of governance and engagement with forests and how it can be designed differently to include more diverse human and nonhuman actors beyond selective expert or elite human actors.

In particular, this project focuses on exploring applications of multiagent-based modeling simulation in the case of urban forest governance in W.H. Vliegenbos. Located in Amsterdam North, Vliegenbos is the oldest urban forest in Amsterdam and the largest elm-rich deciduous forest in Western Europe. While the Vliegenbos foundation is launching its 'vision 3.0' that the forest must become greener and darker for nonhuman species living in the forest (i.e. glowworms, foxes, hedgehogs, martens, hawks, and kingfishers), the tension has arisen with diverse human actors (i.e. tennis club, chemical factory Albemarle, increasing future population in Amsterdam North, and cyclists).

How can the multiagent-based modeling simulation open up more-than-human urban forest governance? How should the computation model and simulation algorithm be (re)designed to include more-than-human perspectives in urban forests? What new modes of engagement and governance with urban forests can be possible by interacting with simulated futures and their trajectories?

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

By conducting research on how the digital twin of Vliegenbos can take more-than-human perspectives and exploring interactions with the simulated future scenarios, I aim to deliver the model specification(A) and concept mockups(B).

(A) The model specification is a document that illustrates the framework and requirements for the computational model. In this case of multi-agent-based simulations, the document will specify a set of agents, their attributes, and interaction rules. In addition, it will provide design guidelines on how to take more-than-human perspectives in designing a computational model.

(B) The concept mockups will visualize how such computational model and simulations can be utilized for deliberative decision-making of diverse human and nonhuman actors (e.g. cyclists, trees, glowworms, and future residents).

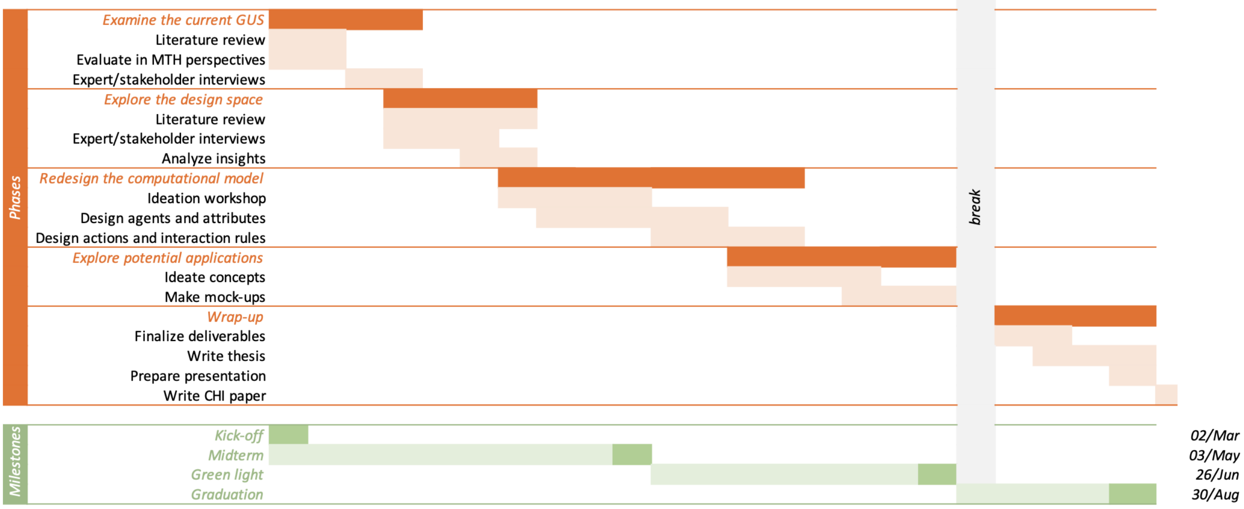
PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 2 - 3 - 2023 | 30 - 8 - 2023 end date

Fulltime (30 EC, 21 weeks)

Schedule																							
Month	*March*				*April*					*May*				*June*					*July*				*August*
Calender week	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
Academic calender week	3.3	3.4	3.5	3.6	3.7	3.8	3.9	3.10	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	4.10	5.1	5.2	5.3	5.4	5.5
Project week	1	2	3	4	5	6	7	8	9	9	10	11	12	13	14	15	16	17		18	19	20	21
Number of days	2	5	5	5	5	4	5	5	4	5	5	5	5	5	5	5	5	5		5	5	5	5
Cumulative days	2	7	12	17	22	26	31	36	40	45	50	55	60	65	70	75	80	85		90	90	95	100



The project follows the Double Diamond design model, which includes four stages: Discovery, Definition, Development, and Delivery. However, each stage has been slightly modified to suit the project's specific requirements. More days have been allocated to the Explore and Redesign stages as it is anticipated that more-than-human design methodologies will need to be tailored for designing computational models. We hope to run actual technical developments and iterative ideations in parallel, but we cannot ensure this since it necessitates collaboration with data scientists.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

Studying design, I have always been drawn to exploring the boundaries of my discipline and discovering connections with other fields such as urban studies, computer science, and science and technology studies. In particular, I was intrigued by complex societal problems that arise in cities, where social, political, technical, and environmental factors are deeply intertwined. This has led me to explore the untapped potential of data and algorithms as design materials, seeking alternative practices of data collection and sensemaking to change the way we understand and interact with the world.

During the DfI program, I acquired key competencies in concept design, experiential prototyping, and visual communication focused on people's interactions with designed artifacts. Through the elective semester, my interest grew sharper in emerging technologies, complex systems, and more-than-human design. Based on the acquired skills and interest, I decided to work as a design intern in a computational social science R&D lab and got more interested in bridging research and practices by translating research insights into visual storytelling and interactive experiences.

Furthermore, through research activities in the field of urban studies and design, I was able to gain more in-depth knowledge on how to frame, analyze, and solve urban issues. For example, writing the first-authored journal (currently under minor revision) for the International Journal of Urban and Regional Research (IJURR) helped me grow a critical lens to examine political ideologies that shape different modes of urban governance. Moreover, being engaged in design research about decentering practices and designerly ways of grasping artificial intelligence broadened my repertoire of possible design interventions. Drawing on these experiences, I aspire to apply my interdisciplinary thinking and tinkering skills to tackle pressing urban challenges.

Through my internship at Lucidminds, I realized that powering green infrastructure with digital twin simulation has significant implications for urban governance and citizen participation. Delving into this agent-based modeling and simulation technology, my ambition is to 1) apply more-than-human design methodologies in developing a computational model of urban forests, 2) explore new modes of visualizing or interacting with simulations of such models, and thereby 3) explore their potential applications to make a societal impact.

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.