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Modelling Workflows for More-than-Human Design: Prosthetic Habitats for the Powerful Owl (*Ninox strenua*)

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Abstract. Anthropogenic degradation of the environment is pervasive and expanding. Human construction activities destroy or damage habitats of nonhuman lifeforms. In many cases, artificial replacement habitats become necessary. However, designing for the needs and preferences of nonhuman lifeforms is challenging. Established workflows for this type of designing do not exist. This paper hypothesises that a multi-scale modelling approach can support inclusive, more-than-human design. The case-study project tests this approach by applying computational modelling to the design of prosthetic habitats for the powerful owl (*Ninox strenua*). The proposed approach simulates owls' perception of the city based on scientific evidence. The tools include algorithmic mapping, 3D-scanning, generative modelling, digital fabrication and augmented-reality assembly. Outcomes establish techniques for urban-scale planning, site selection, tree-scale fitting, and nest-scale form-making. The findings demonstrate that computational modelling can (1) inform more-than-human design and (2) guide scientific data collection for more inclusive ecosystem management.

Keyword: Regenerative design

1 Aims

Human construction activities are pervasive. Their increasing effects on ecosystems are hugely detrimental. The return to pre-human ecosystems is impossible. Yet, even the most heavily modified places can support many forms of nonhuman life. The research presented here seeks to actuate the underutilised potential of cities to support diverse nonhuman life. Existing management strategies, policy, and conservation measures are insufficient to mitigate the decline of urban habitat structures [1]. There is a need to expand existing conservation efforts beyond mitigation and propose concrete design approaches suitable for implementation and testing. Natural urban habitat structures are in short supply. Some, like trees, can take hundreds of years to form. At the same time, the demand is acute. That is why the immediate provision of prosthetic habitats is imperative. Modelling for inclusive, more-than-human design needs to satisfy the needs, behaviours, capabilities, senses and cultural preferences of nonhuman lifeforms. Before moving in, nonhuman life must be able to recognise prosthetic habitats as dwelling opportunities. Therefore, it is necessary to understand what the city looks like from the perspective of nonhuman stakeholders. However, such objectives pose challenges that extend beyond established architectural workflows. Nonhuman clients cannot provide briefs, advise on the selection of sites, discuss their preferences or participate in design reviews. In these conditions, modelling and simulation based on scientific evidence emerge as viable alternatives. Design disciplines can provide a practical focus to scientific data collection and make recent innovations in design technology accessible to interdisciplinary environmental-management teams. In current practice, biological conservation rarely benefits from data-driven design modelling. How can data-driven computational modelling contribute to thriving urban ecologies? The research discussed in this paper hypothesises that a multi-scale modelling approach can support the roles of cities as homes for nonhuman lifeforms.

2 Methods

2.1 The Case-Study

This paper takes as its case-study the challenge of designing artificial habitats for the powerful owl (*Ninox strenua*) in greater Melbourne. The powerful owl (Fig. 1) is a characteristic species that illustrates issues that are common in many other cases. Powerful owls must adjust their behaviour to cope with urbanisation. Owls used to live in old-growth forests [2]. However, fragmentation of forests and the abundance of prey in urban areas compel owls to enter cities [3]. Yet, the lack of nesting hollows means that owls cannot breed in most urban locations [4]. Moreover, even the fast-growing trees take 150–500 years to form hollows large enough to support owl breeding [5]. Thus, there is a need to develop prosthetic habitat structures to house owls within urban areas (and in many other modified landscapes). Existing habitat creation measures, such as nest boxes, are inadequate. Only once has a nest box supported owl breeding, and even then, one of the two chicks died [6]. Existing nest-box designs fail to replicate the affordances of the natural structures. As a result, rectilinear nest boxes can entrap their inhabitants [6]. Their geometry and materials overheat [7]. Nest boxes can be hard to install, and their lifespan is short. Improvements to the characteristics of artificial nests are a complex challenge that spans multiple scales, disciplines, and stakeholders. This paper approaches these challenges by establishing a workflow that (1) describes how owls perceive the city based on current scientific research, (2) simulates this perception and behaviour, and (3) proposes multi-scale interventions according to information identified in these models.

Fig. 1. A powerful owl at a natural hollow. Image credit: Richard Jackson, 2012.

2.2 Nonhuman Perception

This workflow is an outcome of an ongoing collaborative research project that involves architects, engineers, biologists, ecologists, city government, park authorities, and arborists. An interdisciplinary approach facilitates the consolidation of knowledge on owl biology and ethology, helping to understand how owls see the city. The project uses this information to constrain and interrogate spatial datasets that describe urban environments. These data capture the permeability of ground surfaces, presence and types of vegetation, availability of water, distribution of food sources and other relevant aspects. The proposed procedure combines these datasets to simulate owls' perception of the environment. This approximate modelling can help to identify opportunities for future habitation and suggest necessary interventions.

2.3 Multi-scale Modelling

The project deploys modelling on several scales. Its approach supports algorithmic processing and the integration of heterogeneous information from multiple data sources. First, the project builds urban-scale maps and uses them to suggest city-wide regeneration strategies. The second step combines mapping with 3D scanning for the automated selection of sites for prosthetic installations. Third, parametric modelling and augmented-reality construction output prosthetic nests. The multi-scale modelling workflow works by analysing characteristics of discrete cells: 250 m^2 at the urban-scale, 12.5 m^2 at the site-scale, 0.125 m^3 voxels at the tree-scale and 0.025 m^3 voxels at the nest-scale.

3 Outcomes

3.1 Urban-Scale

Single-Channel Vision. The project proposes urban-scale regeneration strategies that use digital mapping to indicate areas for possible habitat expansion. These maps combine multiple layers of data. Figure 2 (top left) shows the road network, an urban feature of high importance for humans. In contrast, Fig. 2 (top right) extracts outlines of riparian (waterway) systems. These areas have vegetation structure and movement corridors that support the ecological needs of owls and many other species that utilise similar resources [8]. This map illustrates the fragmented landscape that cannot sustain large numbers of owls [3].

Dual-Channel Vision. The dual-channel approach identifies patterns relevant to owls. It expresses the likelihood of owls being in (or moving into) an area. For example, the presence of powerful owls correlates with the amount of biodiversity [9]. Accordingly, Fig. 2 (bottom left) shows an aspect of owls' experiential world by mapping the relationship between owl sightings and biodiversity. This map combines data of owl sightings with biodiversity values that show the likely availability of suitable habitats in a location [10]. This mapping helps to highlight the data that designers, developers, or councils need for planning. For example, combined data on prey bases and flightpaths of owls can point to plausible locations for design interventions. Dual-channel mapping can indicate areas that are important for biodiversity conservation but cannot suggest locations for interventions in the areas without owl sightings.

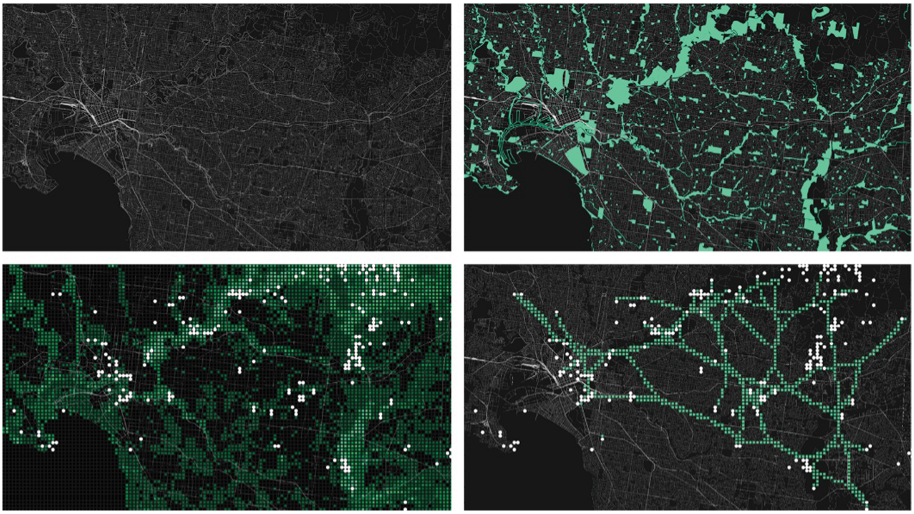

Fig. 2. Urban-scale mapping. Top left: Road network. Top right: Riparian areas. Bottom left: Biodiversity (ranging from 1, black to 100, green) and owl sightings (white dots). Bottom Right: Proposed corridors of connectivity output by the model. Sources: Open Street Map 2018 (all), NatureKit [12] and Atlas of Living Australia [13] (bottom left).

Multi-channel Vision. Addressing this limitation, the map shown in Fig. 2 (bottom-right) provides an example of how simulations of nonhuman behaviour can support planning. This map shows algorithmically generated biodiversity corridors based on known owl dispersal patterns. Owls tend to keep to corridors with high tree cover and good roosting spots when moving through urban landscapes [11] and avoid patches smaller than 200 ha [3]. Accordingly, the generative mapping process uses scripting to (1) cull small green spaces, (2) select remaining parks with known owl sightings, and (3) establish connectivity by drawing and bundling links. This process provides a vision of the possible owl-friendly city and can help to identify realistic opportunities for future habitation. It also indicates the need for further research on the dispersal patterns of owl juveniles. The benefit of this approach is the ability to develop bottom-up, evidence-driven propositions in freedom from the biases imposed by human perceptions that prioritise features important for human societies, such as road networks or municipal boundaries.

Fig. 3. Site-scale mapping. Habitat preferability model with 5 possible values ranging from least preferable (red), to light red, blue (neutral), light green and green (most preferable).

3.2 Site-Scale

The project's next scale demonstrates an approach to the selection of structures (such as trees) for potential design interventions. This approach utilises a 'habitat preferability map' (Fig. 3) which indicates more and less feasible areas. The algorithm calculates preferability as follows (Eq. 1):

$$P = C + T + W + R + B + U, \tag{1}$$

where $P = \{0, 1, 2, 3, 4\}$ is the preferability index (with the possible values in curly brackets); $C = \{0, 1\}$ is tree cover; $R = \{0, 1\}$ roost-tree availability; $W = \{0, 1, 2\}$ is waterway proximity; $R = \{-1, 0\}$ is road presence; $B = \{-1, 0\}$ is building presence; $U = \{-1, 0, 1\}$ is heat-island presence. Characteristics add together to determine the likelihood of owl habitation. Relevant characteristics combine eco-geographical variables that indicate habitat quality [8, 14, 15] with urban features. Preferable habitat characteristics (Fig. 4 left) include the presence of tall trees, appropriate roosting-tree types and proximity to waterways. Undesirable urban features (Fig. 4 right) include roads, buildings, and heat islands. In this model, suitable regions become apparent and measurable. In run, this knowledge helps to select locations for prosthetic additions. In the case of powerful owls, the target structures are living tree types that can form hollows suitable for owl breeding, but which are still too young (Fig. 5). This model can readily accommodate additional datasets as they become available. Examples of relevant information might include data on locations of existing natural hollows, undergrowth vegetation structure, visibility and exposure to people as well as the proximity to known breeding pairs. Published research and expert advice have informed the elements and weighting of this formula. However, its function here is to present an easily adjustable mechanism for multi-criteria design-oriented visualisation, not to demonstrate a complete and precise expression of ecosystem interactions.

Fig. 4. Site-scale mapping. Habitat preferability model inputs. Top left: Tree cover. Middle left: Roost trees. Bottom left: Waterway proximity. Top right: Roads. Middle right: Buildings. Heat islands. Sources: Open Street Maps 2018 (all), City of Melbourne [16] and the University of Melbourne [17] (top left, middle left), City of Melbourne [18] (bottom right).

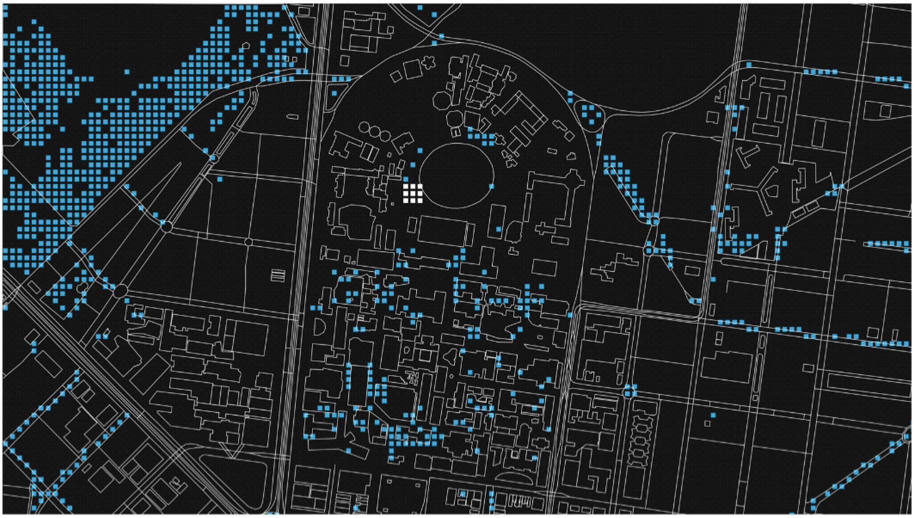

Fig. 5. Site-scale mapping. Identifying living tree target structures (blue). Sources: City of Melbourne [16] and University of Melbourne [17].

3.3 Tree-Scale

With an intervention site selected, the proposed approach employs 3D scanning to place a prosthetic nest on the complex forms of trees. Based on evidence obtained by arborists and ecologists, the algorithmic tree analysis suggests suitable locations. This analysis converts point clouds output by scanning into voxels according to criteria important for humans and owls. Criteria known to influence owls' selection of nests include orientation [19, 20] (Fig. 6 left) and height [6, 21] (Fig. 6 middle left). Criteria important for the viability of an installation include placement at crotch junctions (Fig. 6 middle right) and in areas that are structurally sound (Fig. 6 right). These aspects combine to signpost preferable locations for prosthetic additions.

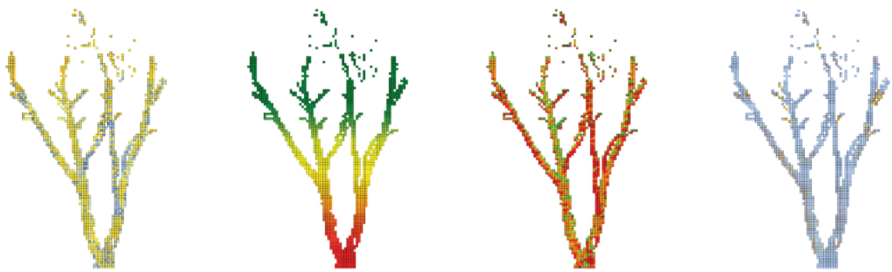

Fig. 6. Tree-scale analysis. Left: Orientation. Middle left: Height. Middle right: Angle of branches. Right: Structural analysis.

3.4 Nest-Scale

The geometry of the host site and the needs of owls determine the form of prosthetic nests. This form mimics the complexity of natural hollows known to successfully house powerful owls. The key form-finding precedent draws on the materiality and geometry of arboreal termite mounds (Fig. 7) which are known to have served as alternative nests. Through the bottom-up activities of termites, these mounds self-organise around trees without damaging them and have favourable internal micro-climates. Figure 8 shows the process for digitally generating analogous forms. The process (1) constructs a mesh that envelops the cloud points around the chosen location; (2) generates the interior geometry and the entrance; (3) textures the surfaces to allow for scratching, climbing, landing and feeding; (4) subtracts the tree's form from the point cloud subset; and (5) generates voxels to merge the meshes into a fabrication-ready unit. Subsequent steps analyse the performance of the resulting models under solar radiation in diverse environmental conditions (Fig. 9 left). These analyses dictate the placement of modules with varying porosities, sizes, or materiality (Fig. 9 right). Augmented-reality assembly (Fig. 10) supports rapid fabrication and testing of full-scale prototypes (Fig. 11). These techniques of form-finding, automated fabrication and assisted assembly are important because design workflows for nonhuman stakeholders need to output numerous units efficiently and be suitable for implementation, customization and installation by non-specialists.

Fig. 7. Nest-scale biological precedents. Left: A powerful-owl chick nesting in a termite mound. Right: An arboreal termite mound. Image credits: Ofer levy 2017 (left) and Blantyre 2012 (right).

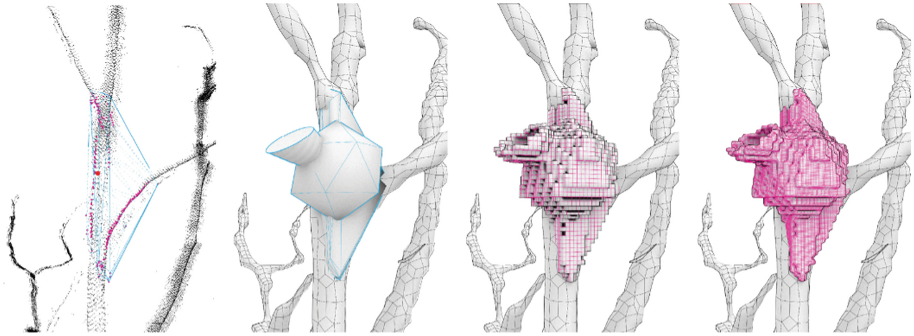

Fig. 8. Nest-scale form generation. Left: Selection of cloud points around the chosen location on the tree. Middle left: Meshes generated to form the interior nest geometry, provide the entrance and landing pad, and attach to the tree's specific geometry. Middle right: Voxels generated around the nest form. Right: Voxels smoothed.

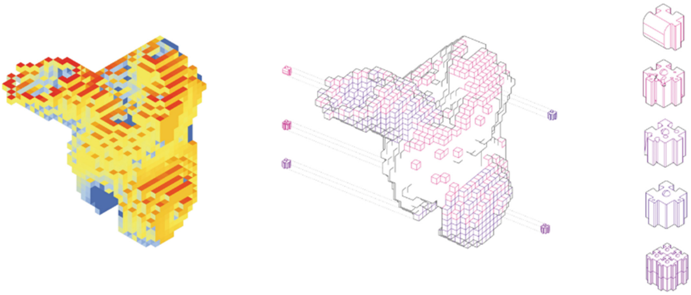

Fig. 9. Nest-scale performance and fabrication potential. Left: Solar radiation analysis. Right: Placement of varying modules.

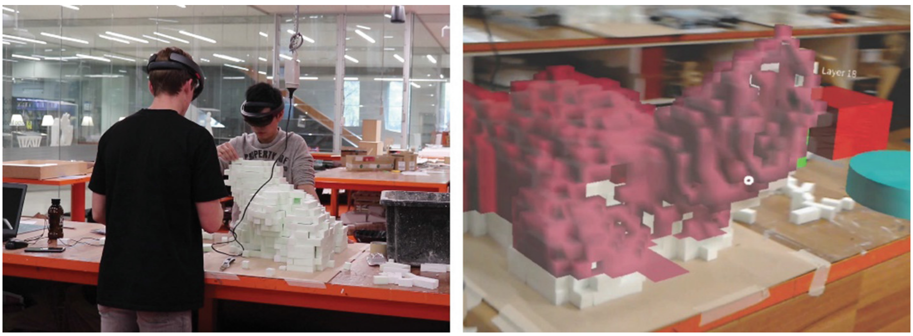

Fig. 10. Nest-scale augmented-reality assembly process. Left: Augmented reality headsets used to guide the placement of modules. Right: Point of view from headset.

Fig. 11. Proof-of-concept prototype on the site.

4 Conclusion

The workflow discussed in this paper demonstrates that multi-scale modelling can contribute to the reconstruction of cities as homes for nonhuman lifeforms. This approach can support designing for many species in diverse environments. The presented project is ongoing and subsequent reporting will describe functional installations and field testing. This paper describes the already-completed work and highlights the importance of computational modelling and its characteristic advantages when designing for nonhuman organisms. Data-driven design is particularly important in the context of designing for nonhuman stakeholders because human intuition cannot reliably assess their behaviours and cultures. Computational modelling can combine disparate data and derive automated recommendations for action or further research. The case-study confirmed such capabilities. For example, mapped flight paths and dispersal patterns of owls can inform planning and design decisions for conservation or regeneration. The conceptualization of modelling discussed in this paper is significant for all forms of design because it addresses the pressing concern of the ongoing environmental collapse. Beyond the urgent necessity, modelling for more-than-human design is exciting because it forces innovative rethinking of the designed forms at the scales from whole landscapes to small objects. In the case of these challenges, generative and algorithmic design processes of form-finding come to the fore and play crucial roles across a broad range of scales, from urban regions to tree bark. In environments that intend to support human/nonhuman cohabitation, further work will have to reconsider design creativity, ethics, aesthetics, usability, safety and other familiar theoretical and practical concerns.

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