Performative Accessories in Multispecies Design: Enhancing Humidity Levels for Plants with 3D-printed Biomimetic Structures

Andrea Macruz[1], Mirko Daneluzzo[2], Hind Tawakul[2], Mona Al Hashimi[2]

[1] Tongji University, Shanghai, China and Dubai Institute of Design and Innovation, UAE
andrea.macruz@uol.com.br
[2] Dubai Institute of Design and Innovation, Dubai, UAE
mirko.daneluzzo@didi.ac.ae; mona.alhashimi@didi.ac.ae

Abstract. The paper moves the design debate from human-centered toward posthuman design, discussing how designers can use a strategy based on Multispecies Ethnography and Participatory Design, considering nonhuman agents to create efficient designs. To illustrate this, it describes a project of 3D-printed biomimetic structures for plants that enhances humidity levels in internal environments. The project methodology started by analyzing the ideal humidity for indoor plants and humans, which is between 40% to 50%. Subsequently, a biomimicry study was done to understand how to generate a cooler indoor microclimate using passive strategies and how to create an effective interlocking system to connect structures. 3D-printed structures as supports for water droplets were designed according to their performance and placed in different arrangements around the plant itself. The structures were tested, and humidity levels increased by approximately 13%. The paper discusses the resultant evidence-based design and a new approach to mass customization.

Keywords: Bio-Inspired Design, Multispecies Design, Biomimicry, 3D printing, Humidity Control.

1 Introduction

For more than three decades, the human-centered discourse has dominated design. However, due to the repercussions of technology and environmental transitions, designers are currently compelled to work on complicated socio-technical systems (Forlano, 2017). The study moves the design debate from human-centered (Norman, 2013) to posthuman design (Forlano, 2017), which considers human and nonhuman agents. It asks how designers may use multispecies techniques (De Ruiter et al., 2005) and Participatory Design (Simonsen and Robertson, 2012) to develop efficient projects.

The paper offers a posthuman interpretation of the term "user," moving away from anthropocentrism and toward biocentrism (Lanza and Berman, 2010). It analyses examples of new design methodologies that emphasize the growing rhetoric of post-humanism (Braidotti, 2013) and proposes that nonhuman lifeforms be included as participants in design research, either as informants and co-designers or as users. To illustrate this, it describes a project that started in an academic course and involved designing a set of "accessories" for plants. The work extends traditional understandings of the "user" to nonhumans and examines the field of action for modern design practitioners, making it a novel contribution to the profession.

The project methodology started with a study based on Multispecies Ethnography and Participatory Design (Gatto and McCardle, 2019) with the observation of discoloration and brown-colored tips of certain leaves caused by a lack of humidity (Iowa State University, n.d). The relationship between indoor plants, humans, and humidity levels was studied, and the ideal humidity levels found between these two species are from 40% to 50% (Koster, 2016; Young, 2020).

Next, a study on biomimicry (Benyus, 2002) was done to better understand how to generate a cooler indoor microclimate using a sustainable passive strategy (Khelil and Zemmouri, 2018) without relying on electricity and how the structures could be connected effectively using the same material. Three biomimicry case studies, the Darkling beetles (AskNature, n.d), Warka Tower (AskNature, 2017), and Birds Feather Interlocking Systems (AskNature, 2018), were used as examples to design the geometry of the structures for better efficiency. 3D-printed biomimetic structures as supports for water droplets were designed. These design decisions became beneficial and evolved according to their performance. The structures can be combined and arranged in different ways around the plant as architectural elements staged around the individual plant specimen. These arrangements were important because they allowed for an evidence-based design tuned for maximum performance and plant health. Humidity levels of the structures were measured using an in-door hygrometer, Inkbird ITH-20, and it was noticed that they increased by approximately 13%.

The paper discusses the resultant evidence-based design and a new approach to mass customization. The findings pointed us to a deeper understanding relative to nonhuman design, ergonomics, humidity control, and design performance to gain insight into desirable nonhuman situations.

2 Posthuman Design and Multispecies Theory

The conventional dualistic systems of natural and artificial, human and animal, and human and machine are blurring due to technological developments. They emphasize nonhumans' new kinds of agency in the world, whether it's environmental or technological. A growing body of social theory has sprung around concepts aimed at making sense of this blurring of lines and introducing hybrid, non-dual, relational modes of thinking (Forlano, 2017). This paper focuses on one of these hybrid modes of thinking, specifically the posthuman, for a design approach that significantly increases our awareness of the numerous agencies, dependencies, entanglements, and linkages arising from current design challenges and questions (Forlano, 2017).

The human-centered design methodology is a practice where designers focus on human needs (Norman, 2013). However, humankind is just one of many variables that shape our environments, and its agency is constituted through relational processes rather than predetermined (Gatto and McCardle, 2019). As design moves into the social sector and deals with issues in complex socio-technical systems, it's critical to change this approach to a broader one, such as a posthuman design, considering human and nonhuman actors. The work being done in post-humanist and post-anthropocentric disciplines argue that we should start thinking of manufactured systems as networks that encompass a variety of living creatures and the agency structures that act in and around them to better understand our planet's transitions.

Moreover, design does not have to be seen as an affirmative discipline but rather as a process-oriented analytical tool. One area open to investigation is re-interpreting man's connections with other species and the environment, proposing future multispecies cohabitation scenarios. To experience multispecies worlds to understand environmental issues, designers must get familiar with numerous techniques designed to be more than just a set of procedures but also distinctive ways of behaving, thinking, and experiencing (Gatto and McCardle, 2019).

The term "multispecies" was first mentioned in the fields of biology and ecological sciences more than a decade ago to describe patterns of co-construction of environmental niches and wildlife management (De Ruiter et al., 2005). Its fairly recent introduction into the study of anthropology has allowed for new interpretations of the concept, helping us reevaluate how nonhuman agents interact with design and associated processes. It also broadens the definition of sustainability because tackling environmental problems from nonhuman viewpoints can produce different results from those predicted by technocentric approaches (Gatto and McCardle, 2019).

The paper proposes a design that engages human and plant perspectives to create a multispecies reading of the concept of humidity in interior spaces.

3 Theoretical Underpinnings for Methodology

3.1 Multispecies Ethnography and Participatory Design

Ethnographic research is a design process that uses observational and interview methods to understand better the people who will utilize the developed products. The fundamental hypothesis is that a detailed understanding of people's lives, habits, motivations, and challenges might lead to better proposals or, at the least, more pertinent design suggestions. Long-term immersion in their subjects' lives, including participation in their everyday activities, is a hallmark of anthropologists and ethnographers. They engage in various actions, such as observing, taking pictures, recording, making notes, and conducting interviews. Based on these activities, they generate theories, texts, and publications to demonstrate their academic credibility (Nova, 2016). Designers utilize this information and ethnographic tools to create original concepts, develop ideas, and implement them (Van Dijk, 2012).

However, beyond standard ethnographic research, this project was based on Multispecies Ethnography, a more-than-human perspective on the ethnographic study gaining traction in anthropology and related fields. In this context, the terms “interdependent” and “inseparable” are used to characterize work that acknowledges the interconnection and inseparability of people and other living things, striving to expand the scope of ethnography beyond the limitations of the human experience (Münster, 2015). Multispecies ethnographers are starting to trace genes, cells, and organisms through landscapes and seascapes to learn how elements of Homo sapiens are producing becomings in the bodies of other species, as well as the converse. (Hayward and Kelley, 2010). Differently from Multispecies Ethnography, the research location for this project was not an open field; the chosen place was an indoor environment, inside a house, because that is where daily interaction of nonhumans and humans occurs.

The concept of multispecies offers new perspectives on how nonhuman individuals fit into the design and its related practices. Participation in design can be interpreted as a dialogue between many users (Lawson, 2005), but things can get complicated when participants aren't actual people. Before we can accept the agency of other-than-humans, we must first experiment with design solutions that can help us hear what other-than-humans want to "say" and, considering that, come up with alternatives to our social, cultural, and economic models (Gatto and McCardle, 2019). The primary focus of participatory design study and practice is on human participants. Nonhumans, however, can also participate in the design process and significantly influence how it is carried out.

The paper expands on that idea and analyzes indoor plants' ergonomics, the ideal conditions for them to thrive, their relation to humans, and how plants and people establish a mutualistic relationship in a win-win scenario. Ideal humidity levels are essential for both species to survive; therefore, improving one will surely benefit the other. The theory holds that co-performance (Kuijer and Giaccardi, 2018) promotes greater cooperation among humans, nonhumans, and the environment while allowing both species to thrive. Lovelock extends this idea by posing the earth as a self-regulating entity (Lovelock, 2016).

3.2 Biomimicry Strategies

The discoloration on certain leaves, caused by a lack of humidity in specific conditions (Iowa State University, n.d) and the research on the ideal humidity levels for plants and humans led to the idea of creating 3D-printed structures for plants that would generate a cooler microclimate in internal environments.

Another step involved biomimicry research (Benyus, 2002) to better understand how water could increase the humidity of indoor environments through a sustainable passive strategy (Khelil and Zemmouri, 2018) and how to create a performative interlocking system to connect structures with the same material.

The first two biomimicry case studies were related to how nature collects and retains water. The first one was the Darkling beetles of the Namib desert. To survive, some species of these beetles include unique points and bumps in their wing scales that aid in water collection. Water droplets occur as air condenses on the tips, which run off the bumps and into the beetle's mouth (AskNature, n.d.). The second one was the Warka Tower, a biomimetic project inspired by the beetle that similarly gathers atmospheric water vapor from rain, fog, or dew which condenses on the polyester mesh's cool surface, generating droplets of liquid water that flow down into a reservoir at the structure's bottom (AskNature, 2017).

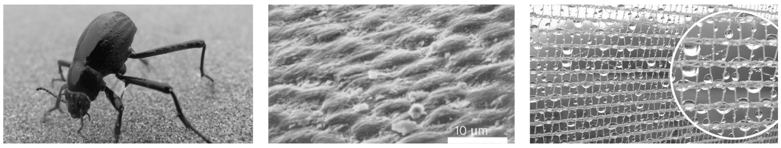

Figure 1. Darkling Beetle, scanning electron micrograph of the textured surface of the Darkling beetle's overwing; atmospheric water vapor condensed on the Warka Tower mesh's surface. Source: https://asknature.org

The third biomimicry case study was the Birds Feather Interlocking Systems in which filaments of birds' feathers connect with interlocking hooks and work as a "natural" zipper. A feather's central shaft has approximately a hundred filaments on either side, each fringed by a hundred smaller filaments called barbules. The birds comb with their beak the disarranged feather's filaments, which are pressed together. The barbules' hooks reengage like the teeth of a zip-fastener, restoring a smooth and continuous surface (AskNature, 2018). These three biomimicry case studies were considered for the shape and geometry design of the structures for better performance.

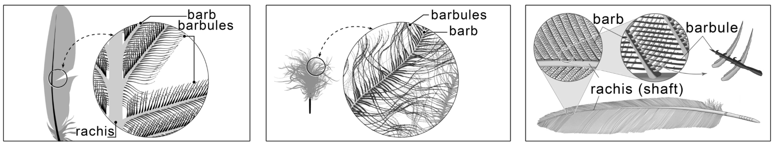

Figure 2. Feathers' interlocking. Source: Mya Thompson, 2014; Brittanica, n.d.

4 Methodology

The project methodology started with a study based on Multispecies Ethnography, analyzing the discoloration on certain leaves of indoor plants caused by a lack of humidity in specific conditions (Iowa State University, n.d). Many humans and nonhumans suffer from low humidity levels, especially in dry climates. So, the relationship between indoor plants, humans, and humidity levels was studied. The ideal humidity levels for humans are between 30% to 50% (Koster, 2016), and for indoor plants are from 40% to 60% (Young, 2020). There is an overlap of ideal humidity conditions for both species, indoor plants and humans, between 40% to 50%. When designing to enhance one's performance related to humidity levels, the other will automatically increase, following the concept of co-performance (Kuijer and Giaccardi, 2018). This research led to the idea of creating 3D-printed structures for plants that would generate a cooler microclimate in internal environments that could benefit nonhumans and humans.

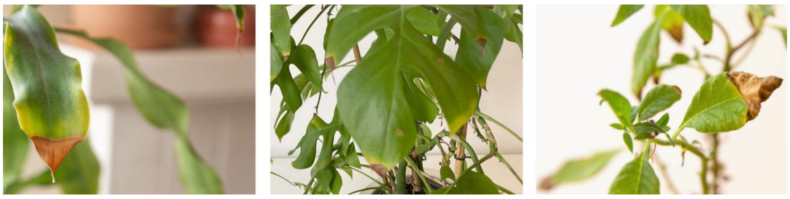
Figure 3. Discoloration on indoor plants' leaves. Source: Krystal Slagle, 2022.

Also, in this project, the idea of accessory or adornment (Maykut, 2014) became relevant, extending to nonhumans the same care and attention that people have when interacting with their bodies, as well as Participatory Design (Simonsen and Robertson, 2012) to be conscious of how ergonomics perform when designing for nonhuman bodies and enhanced efficiency.

The design of the structures started with decisions on the external shape that had to be easy to compose but also strong not to bend or break. Considering that the triangular shape, and its derivations, are stronger than the rectangular shape, and they can fold in a non-orthogonal way, the external shape was designed as arrangements of triangles. One method Buckminster Fuller would describe the differences in strength between the rectangle and the triangle is to apply pressure on each. The rectangle would fold up and become unstable, but the triangle can withstand the pressure and is far more rigid–in fact, it is twice as strong–than the rectangle (Buckminster Fuller Institute, n.d.)

In parallel, textures were studied based on the Darkling beetles (AskNature, n.d.) and Warka Tower (AskNature, 2017) to understand how water droplets could be stored within a mesh. However, the 3D-printed biomimetic structures wouldn't harvest water from the air, unlike the previously mentioned examples. The proposed structures would serve as supports to accommodate and store sprayed water, creating a cooler microclimate for indoor plants, the main users, and humans. An object that would interact greatly with the plant should be made of natural or biodegradable materials. In this case, compostable bioplastic, PLA, was used and water. Also, they should be lightweight, have a system to connect, and grip different steam sizes to better adjust to the plant's ergonomics. They were 3D-printed as flat structures and later folded for efficient storage and transport, like origami.

Parametric definitions were generated using Rhinoceros and Grasshopper. Different meshes were tested, calibrating the pattern and the layering. The initial approach used sinusoidal wave patterns in a 2.5D configuration, with overlapping and non-overlapping layers. The cases with overlapping layers responded better, storing water in-between the waves due to surface tension. Other meshes with 1, 2, and 3 layers of 3D-printed PLA were tested, and the one that performed better was the two-layered one. The one-layered mesh was not enough to store a good amount of water droplets, and the three-layered one, although it could hold more water droplets, was not malleable and quite heavy (Figs. 4 and 5).

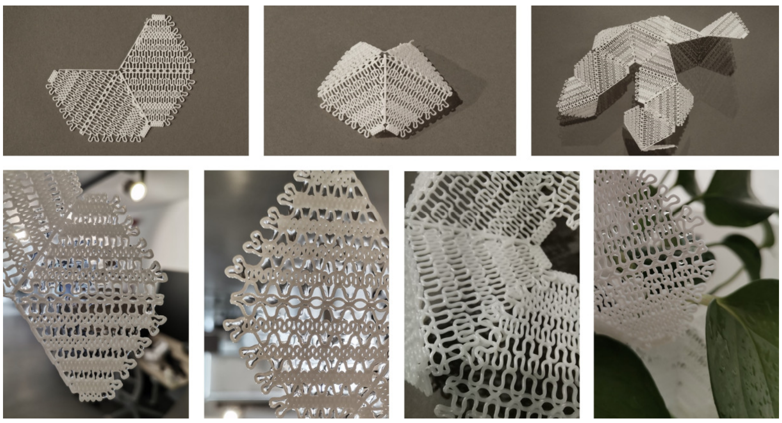

Figure 4. Initial structures: flat, bent, connected with others; structure with water; a close-up of the structures' interlocking system; and the structures arranged on a plant.

The second approach evolved the pattern to a 3D configuration using a calibration between the toolpath geometry and the extrusion parameters. In this case, water is stored as droplets in the three-dimensional structure, and the one-layered performed better than the others (Fig. 5). The one-layer 3D configuration is enough to store a good amount of water, maintaining its lightweight and strength. The two- and three-layered ones were not malleable and quite heavy. Therefore, the chosen mesh for the final structures was the one-layer 3D configuration – P4-1 (Fig. 6).

Throughout the process, it was important to use sprayed water because, in dry climates, people already spray indoor plants' leaves with it, so it is a standard and interesting procedure that helps the two species bond. In this case, the only difference would be that the water retained would be enhanced using these structures.

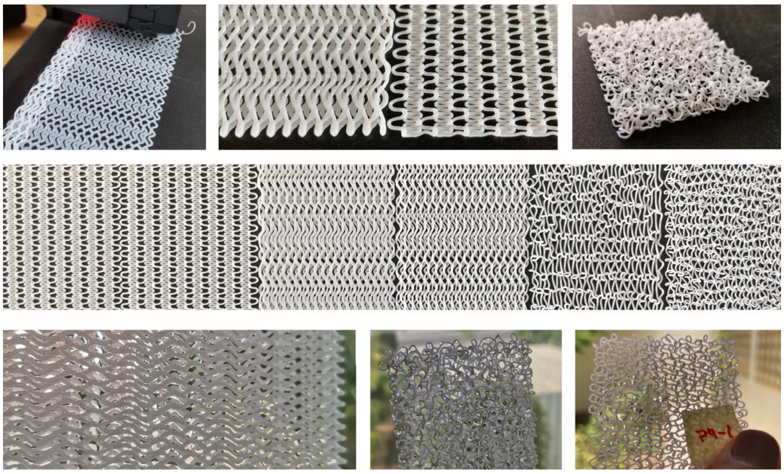

Figure 5. Meshes with 2.5D and 3D configuration.

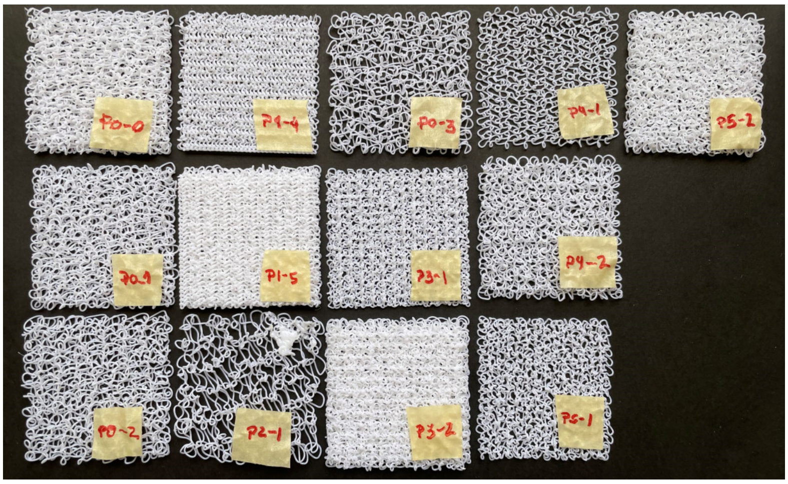

Figure 6. Meshes with 3D configuration. The one that performed better and therefore was chosen for the final structure was the P4-1.

Observing that the mesh had undulations on the outer part, which could be used to join the structures, it was decided that there wouldn't be different typologies but just one that would allow multiple connections. For that, the undulations on its outer part were exaggerated to make the interlocking system more stable, and another biomimicry strategy was applied related to the Birds Feather Interlocking Systems (AskNature, 2018). The interlocking systems of the structures were designed according to a fractal-like organization and configured according to their performance and grip-ability to the plant's stem. An open-ended possibility of combinations was created using an interlocking system of a standard module without using another material.

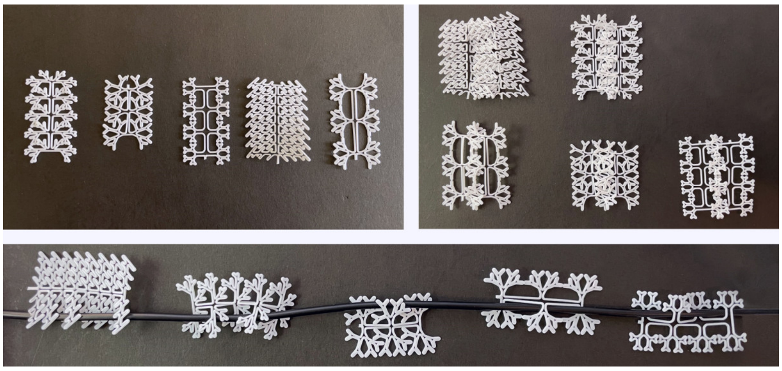

Figure 7. Interlocking systems designed according to a fractal-like organization and configured according to their performance and grip-ability to the plant's stem. The one that performed better and was chosen for the final structure is the one in the middle on the first photo and the end on the second and third.

After the tests above, the structure's design was simplified to a rhombus formed by two triangles rather than four. The structures were 3D-printed in two sizes to fit better with plants' different types and body parts: a bigger one with approximately 10 cm x 7 cm and a smaller one of about 8cm x 6cm.

Also, the joint connecting the two triangles of the structure was part of the sinusoidal weaving strategy of the pattern in the initial tests. That generated geometrical continuity, but it was difficult to bend, and, in some cases, it broke, compromising the system's stability. On the structure using the 3D mesh, the joint was modified to a square wave to facilitate the bending in different directions. In the final configuration, the distance between the triangles was reduced to enhance stability and continuity between the modules (Fig. 8).

Next, 30 structures of the bigger size and 25 of the small ones, 55 in total, were arranged around a plant in an indoor environment that didn't receive direct sunlight to prevent the evaporation of the water embedded in them. The structures were combined and arranged in different ways around the plant itself, as an architectural element to be staged around the individual plant specimen and according to how much weight the plant could support in each part, culminating in different performative qualities. These arrangements were important because they allowed for an evidence-based design tuned for maximum performance and plant health. The plant with the structures was put inside a cardboard box to measure the humidity level with an in-door hygrometer.

Figure 8. Different joint types and sizes; test for the grip-ability to the plant's stem, structures with different meshes. The one that performed better and was chosen for the final structure was the P4-1.

5 Results, Discussion and Conclusion

The structures were placed inside a white cardboard box to measure the humidity level with a standard in-door hygrometer, Inkbird ITH-20. The initial humidity level was 42%, and after water was sprayed on them, the humidity level increased to 55%. When this last step was repeated with the structures arranged around a plant, the humidity level changed to 63% because the plant helps to retain the water droplets. As indoor plants need humidity levels from 40% to 60% (Young, 2020), the structures provided quite an effective change in humidity. Since plants can co-exist in indoor environments, contributing to different humidity levels, the concept of co-performance (Kuijer and Giaccardi, 2018) expands our sense of inter-dependence with other species, helping each other to regulate beneficial conditions.

Figure 9. Structures without water (42% of humidity) and with spayed water (55% of humidity); structures arranged around a plant without water (42% of humidity) and with sprayed water (63% of humidity); structures arranged around a plant and close-ups.

This paper advances the design discussion toward post-humanism, which considers human and nonhuman agents, the last typically disregarded in design procedures. To gain insight into desired nonhuman settings, it starts with an interdisciplinary discussion that links recent research in nonhuman design, ergonomics, design performance, and ideal indoor humidity levels. It also details the development of a project of "accessories" for plants that culminated with 3D-printed biomimetic structures as support water droplets, placed in various patterns around a plant to increase humidity levels in indoor environments. The findings reveal that just the structures without the plant increased humidity by approximately 13% and with the plant by 21%. The results imply that considering nonhuman actors can lead to different design proposals and a mutualistic relationship scenario based on the concept of co-performance.

The paper creates a new approach for working with plants as nonhuman actors and recognizing the potential of "other-than-human" capabilities, making a fresh addition by extending conventional understandings of the "user" to nonhumans and linking it with 3D printing and mass customization. It explores the evidence-based design that resulted and the environmental ideals we want our society to embrace, with implications for future design rules and practice.

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