Wax Arts With Honeybees – Taking First Steps Toward Multispecies Co-Creation

Stephan Huber
stephan.huber@uni-wuerzburg.de
Chair of Psychological Ergonomics, Julius-Maximilians-Universität
Würzburg, Germany

Tamara Friedenberger
tamara.friedenberger@uni-wuerzburg.de
Chair of Psychological Ergonomics, Julius-Maximilians-Universität
Würzburg, Germany

Parzival Borlinghaus
parzival.borlinghaus@kit.edu
Institute for Operations Research, Karlsruhe Institute of Technology
Karlsruhe, Germany

Sara Wolf
sara.wolf@uni-wuerzburg.de
Chair of Psychological Ergonomics, Julius-Maximilians-Universität
Würzburg, Germany

Figure 1: Process overview of our co-creative project from bees' natural building style to what they sculpted from our starter objects.

Abstract

Centuries of beekeeping restricted the honeybees' role to a producer of raw material, such as honey or wax, which is then harvested and processed, resulting in all artistic value being added by humans. In this project, we regard honeybees (*Apis mellifera*) as co-creators and explore the joint creations of our two species. During our first season, we scoped the co-creative space over the course of four months. We present image material of sculptures that exceed bees' natural building behavior and contribute preliminary insights on artifacts originating from human-bee co-creation. We reflect on how human-introduced wax shapes made the bees deviate from their regular comb forms and discuss future paths of multi-species co-creation, temporality, material as well as ethical aspects. Our preliminary insights raise questions to be developed in discussions with the TEI community and answered in future work during the upcoming bee seasons.

TEI '25, March 4–7, 2025, Bordeaux / Talence, France

The definitive Version of Record was published in *Nineteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '25), March 4–7, 2025, Bordeaux / Talence, France*, https://doi.org/10.1145/3689050.3705990.

CCS Concepts

• **Human-centered computing** → **HCI theory, concepts and models**; *Field studies.*

Keywords

Multispecies, Honey bee, Co-Creation, Animal centered

ACM Reference Format:

Stephan Huber, Tamara Friedenberger, Parzival Borlinghaus, and Sara Wolf. 2025. Wax Arts With Honeybees – Taking First Steps Toward Multispecies Co-Creation. In *Nineteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '25), March 4–7, 2025, Bordeaux / Talence, France.* ACM, New York, NY, USA, 8 pages. https://doi.org/10.1145/3689050.3705990

1 Introduction

"In nature, nothing exists alone", biologist Rachel Carson noted in her great work Silent Spring [11]. The world we live in is inherently shared between diverse species and biosystems. Thus, it is unsurprising that the HCI community, more generally, and the TEI community specifically shows an increasing interest in expanding their areas of interest towards multispecies concerns (e.g., [3, 4, 19, 27, 32]). Previous work in this realm has (1) designed technologies to observe and track other species (e.g., [18, 33]), (2) designed for and with other species (e.g., animal-computer interaction (e.g., [23, 25])), (3) integrated other species in the design of interactive installations (e.g., algae, kombucha scoby, microbe; [4, 10, 12, 28]), or (4) reflected on what it might mean to design with another species (e.g., [18, 32, 39, 40]). While these reflections are often speculative, our ongoing research through design (RtD) project [43] aims to explore hands-on what it might mean to co-design with another species, specifically honeybees (*Apis mellifera*).

Our project is thus similar to projects in the context of animal-computer interaction which focus on realizing participatory engagement of animals in the design process (e.g., [26, 41]), but there are also significant differences. While studies in animal-computer interaction focus on designing interactive technologies for animals, our project takes a broader perspective following Light et al.'s call to look "at the balance and impact of our digital next steps, for all, with all" [22, p. 8]. Similarly to Søndergaard and Campo Woytuk, our goal with this project is not necessarily to design a concrete digital technology, but to contribute to the growing conversation on incorporating non-digital, biological materials like beeswax in HCI research and to explore the (technologically mediated) process of co-designing with bees as a non-human species with its related design space [34].

At the intersection of technology design and honeybees, research so far has focused on facilitating the management and scheduling of beekeeping activities or optimizing gear for surveying bee populations, e.g., [7, 9]. An interesting perspective is that bees can serve as biosensors [8], helping map floral biodiversity through their pollen collection activities within the apiary's perimeter. Within HCI, research with and about bees is often similar: Researchers take inspiration from the bees' example, e.g., the honeycomb structures, and apply similar principles to develop novel materials (e.g., shape-changing materials [30]). Similarly, inspiration is taken from bees' movements [1], and wax or honey is often taken from the bees so humans can make something else from them. In response to these observations that "collaboration" with honeybees is often based on extraction and only to optimize procedures for human purposes or "in order to" (do something else), we wanted to explore whether alternative forms of collaboration with honeybees are possible. More specifically, we wanted to explore whether honeybees could be seen as independent contributors in co-creative sculpturing rather than mere bio actuators whose agenda can be understood to the degree that their construction contributions can be programmed similarly to a 3D printer. The project was inspired by a fascinating observation: Whenever honeybees have space, they build incredible structures with their self-produced wax and propolis (see Figure 1, phase #1). This work-in-progress reflects on the first season of co-designing with bees, presenting tangible artifacts, insights, and future directions to inform ongoing inquiry as the next season begins next summer.

2 Design Research Process

In this project, four humans collaborated with two honeybee colonies. Among the four human co-designers, three had backgrounds in HCI, two in beekeeping, and one in computing in apidology. The bees' skills cannot be introduced on an individual level; however, honeybees in general are almost born as creators, in that they spend the 10^{th}–20^{th} day of their life building [37]. Not only do they form the familiar comb structures and isolation of the hive's outer walls, but they also synthesize the material mostly themselves by sweating out flakes of wax [6, 37]. Depending on the availability of resin-rich trees, they also gather and enrich their wax structures with propolis. In contrast to the agricultural harvesting of raw material, in this project we esteem the creative abilities of the bee-made solid structures. We appraise their wax contributions as art rather than raw material and curiously explore what changes they apply to human-made artifacts using their mouthparts, claws, and wax glands. For the sake of brevity, in this work we only report on the interactions and experiences with one of the two hives involved.

Our four-month (May-August) design research process can be summarized in six phases as visualized in Figure 1: (1) we observed how bees build naturally in the wild as well as in human-made hives; (2) we provided a custom frame featuring a small cave designed to serve as an atelier-like design space for the bees; (3) we added small geometrical objects made out of wax sheets as "starters" in this space; (4) we exchanged the design space with a larger one which featured a wide-angle infrared camera and allowed for capturing and saving pictures and short video clips locally to a Raspberry Pi; (5) we regularly inspected the colonies' creative progress and exchanged objects with new ones (mostly all-wax but also a wax-coated LED-strip and USB drive) on three occasions; (6) we finally extracted the design space together with the resulting artifacts thus re-establishing the original hive order.

2.1 Resulting Tangible Artifacts

The bees significantly changed the simple tangible wax objects provided by us, sculpting them into unique artifacts. They gnawed bits off, extruded comb structures (Figure 3), melted wax plates through their mass-presence enough for the plates to bend, and merged objects together, forming novel shapes. For instance, over three weeks, they transformed a bland rolled candle into a multi-folded wax sculpture (Figure 2) beyond recognition of the object it started from. The next section presents a detailed analysis of bees' artistic contributions along with our learnings and future questions.

3 Reflections and Future Paths

In the following, we will discuss a number of overlapping themes that arose from our initial co-creation season. We will close each theme with further questions to be answered in upcoming seasons.

3.1 Multispecies Co-Creation

Humans' documented interest in honeybee research dates back to Aristotle [35]. Gaining a glance into the hive in the past required opening it or building a transparent hive [29]. Today, small cameras allow us to unobtrusively watch bees as they build comb structures. From centuries of honeybee research we know a lot about their anatomy, sensory abilities, communication patterns, social behavior, and productive work life. However, as we cannot apply qualitative methods to interview the honeybees and drill down to their non-human psychological motives or emotions-like states, all our endeavors are restricted to an outside perspective – we will never know "what it's like to be a bee" [13, p. 3]. This, of course, limits our claims about the bees' role and perspective in this co-creative process. In our project, the bees' contribution was mainly to change the wax structures. They are physically able to contribute new wax, but judging from the shape of the emerging structures they gnawed more off than they added. From a stance of co-creational awareness we can not assume that the bees recognized our objects as an invitation to contribute art. In contrast to previous artwork where bees were merely extruding structures [21], that is, executing a task predefined in detail, we had no concrete tasks for the bees but let them engage with, add to, and remove from the objects freely. While our co-creators deliberately transformed the wax structures (i.e., we did not treat the wax with a baiting substance and did not punish bees for non-participation), their goals likely diverged from ours. For bees, building cells is primarily about creating distinct room for brood and food storage and likely less about creative development. The uncertainty of what bees thought about the collaboration or even co-existence leaves room for speculation and future research:

3.1.1 Bee2bee. When observed over time, the bees' design process appears remarkably coordinated, despite the involvement of hundreds. The behavior of *individual* bees, however, seems disorganized, as if "every insect is pursuing its own agenda without paying much attention to its nestmates" [36, p. 1]. Behavioral researchers explain this apparent contradiction through the role of the environment, which serves bees as a "carrier of stimuli". Individuals organize nest structures in a way that stimulating elements emerge [31]. These structures, in turn, can "direct and trigger a specific action from any other individual from the same species" [36, p. 6]. Because individuals respond to the same stimuli in a similar way, no central organization is required; the structure itself contains all the necessary information about the next steps to be taken. However, it is unlikely that bees are preprogrammed for every conceivable structure. What disruptions arise when human intervention confronts the bees with art(ifacts) that the bees were not prepared for?

3.1.2 Hive2hive. To visit another hive in nature, (1) an individual worker bee may permanently join another hive if she becomes lost or if her birth colony is struggling, a phenomenon known as "drifting" [15]. Alternatively, (2) half of a colony may swarm off to search for a new home with their old queen [37]. In neither of those occasions do they move with an already built comb. (3) Collectively visiting another hive to rob it is common when resources are scarce but usually leaves the combs destructed [37]. Therefore, multi-hive construction projects do not exist naturally. Switching frames with comb between hives is practiced intentionally by beekeepers to re-distribute resources, combine colonies, or unwittingly return honeycombs after extraction to the "wrong" hive (bees likely don't care). Multi-hive co-creation, therefore, requires a human beekeeper as facilitator. Will two colonies develop different building styles when given the same wax objects? Does switching these objects between hives mid-creation enhance creativity or cause disruption?

3.1.3 Hive2human. What role does the colony assign their beekeepers? Standing outside the matriarchy of a colony, are beekeepers seen as *foragers* who steal essential resources, *shepherds* who provide shelter for the colony and protect from pests, or *managers* who skim excess resources after a rich harvest and top up the storage during dire autumn times? Or is the beekeeper even something more powerful, being protected against stings, carrier of smoke, opener and mover of hives, a divine being caring for dozens of colonies, surviving generations of bees?

3.2 Temporality

Bees have a natural cycle of breeding and building phases across the seasons [37]: Outside of summer, the bees do not actively build or need time to prepare for winter. Thus, our co-design time frame is confined to around four months (May-August). Sadly, our chance to react directly to the bees' current contribution was very limited. Our bee hives are stationed in a rural area with limited electricity and Wi-Fi access. This meant that we could only engage with the bees in "design meetings" which included taking a look at their past work and the camera feed, as well as introducing new materials at the same time. As a result, we had to ideate and build our design input objects prior to our meetings while the bees were working on the last set as the location of the bee hives did not accommodate well for human design work. Additionally, as the bees' activities remained quite unpredictable to us (which objects they would take wax from, build out more, or just ignore), our rationale for each of our design contributions included a lot of conjectures.

Taking a step back and zooming out, we reflect on another aspect of temporality – namely, the differences between species. For us, the interaction and co-design project happens in one relatively small timeframe of our lives, but even one bee season necessarily spans multiple generations of bees.

Thus, several questions remain open: How can we increase the interactivity and our ability to directly respond to the contribution of our bee co-creators? Besides a camera feed, what connections could be made to gain more insight into the bees' design activity? Will the generational shift in a bee colony change the co-creation process, and if yes, how?

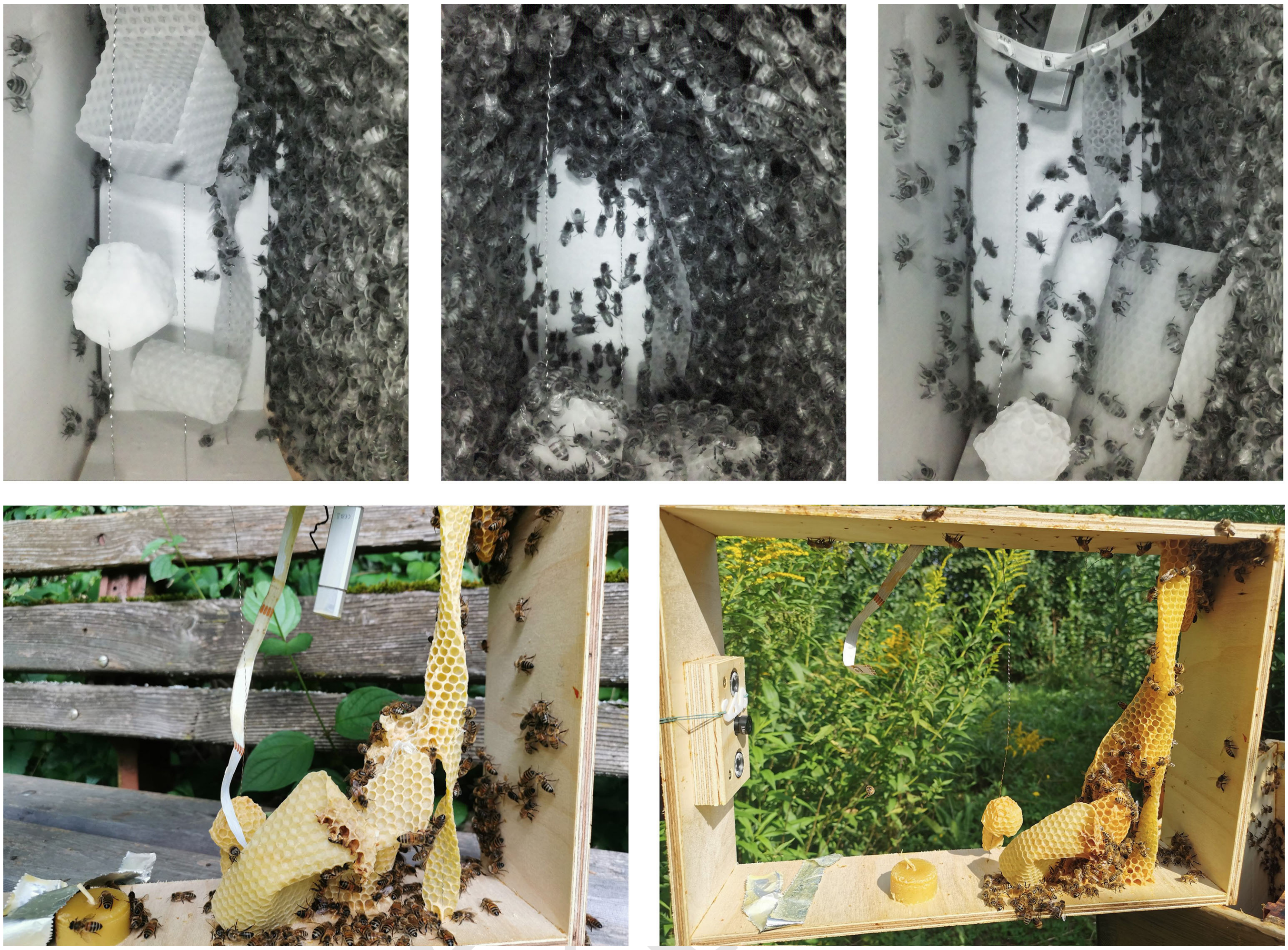

Figure 2: Top row: infrared camera feed from the monitored design space in phase #4 (left, middle) and phase #5 (right); note how the objects slid down the wire through the heat and weight of the colony. Bottom row: reconstruction and deformation of supplied objects, in phase #5 (left) and after phase #6 (right)

3.3 Material

Another focus of our reflections is the material. This can be viewed on two levels: either as beeswax more generally or as the co-designed bee-and-human-made structures showing the classic honeycomb patterns. In the following section, we reflect on a select number of material aspects from the interaction material profile suggested by Döring [14].

3.3.1 Wax as a Fuel. One of the most prevalent use cases for beeswax is candle making. The wax serves as fuel in this case, "disappearing" when a candle is burned, adding another aspect of temporality and a possibility of conveying additional metaphorical meaning for specific applications [14]. We introduced several beeswax candles into our design space - two poured candles and two rolled candles, with one of them being partially unrolled, see Figures 1 and 3. The poured candle was only nibbled (or maybe dented by bee legs, see Figure 3, middle), but the rolled candles got worked on extensively (see Figure 4, middle and right). Interestingly, the bees gnawed the wicks of the candles beyond recognition, preventing the intended use of candles from being burned, see Figure 3. The co-designed shape of the wax structures does not meaningfully impact the material properties when used for fuel. Any benefit added here would come from the expressive potential of the structures, lending itself more to one-off, personally meaningful objects. Harking back to our reflections on entangled temporalities, could bees rework a candle while it is burning or even constantly "refuel" a slowly burning candle, approximating an eternal light?

3.3.2 The Changeable Nature of Wax Structures. Wax in itself is quite changeable, being biodegradable and easily deformed by adding heat and applying little force. This can be seen when comparing the introduced partially unrolled candle from Figure 1, phase #5, with the construction progress in Figure 2, where the introduced wax structures were heat formed by the bees' body temperature

Figure 3: Design Objects before (left) and after (middle, right) bees' design activity

and gravity (possibly combined with the bees' weight): The unrolled part of the candle begins to slope and sag more and more. This means that the mere presence of the bees changed the wax structures. Similarly, when looking at the design progress, we introduced unintentional changes to the structures as well: removing the design space from the hive as well as removing individual structures from the wooden hive boards results in breaking off wax connections between bee combs, or potentially shifting objects around. The changeability of wax structures limits future applications, as any direct handling will deform the structures over time. On the other hand, this general material aspect opens new use cases, for example using the extracted wax structures as a tracing method for technology usage over time, giving the slow morphing and changing of the structures additional meaning. Regarding the macro material aspect of sustainability [14] and similar to other biodegradable materials [2], the wax structures can be repeatedly melted and reintroduced to the bees as a wax reservoir (potentially already shaped by pouring into a mold), providing new material for future iterations without requiring the bees to produce more wax. So we ask how the changeable nature of the designed wax structures can be utilized in technological artifacts?

3.3.3 Wax Structures as an Insulation Material. We explored if our co-created wax structures could be used as an insulating material, covering technological objects. Similar to how dipped candles are made, we pre-coated our introduced objects (an LED strip and a USB drive) in beeswax by repeatedly dipping them into molten wax. The bees almost completely ignored our tech-based inputs, see Figure 2, raising the question of whether the tech objects were aversive to the bees or just unappealing. If the technological objects are aversive to bees but desired by human co-creators, how could structures be merged with technological components after removing them from the hive?

3.3.4 Wax Structures as a Habitat and Food Resource for other Species. After removing some objects from the bee hives, we found that they had become infested by wax moths - a species of moths that breeds and hatches inside honeybee hives and, while searching for protein-rich pollen, also consumes wax structures [37]. This highlighted the multi-species interconnectedness of centering a natural material like wax for us as well as for our project in general. We froze uninfested objects to conserve their current state from moth activity and decided to leave other objects intentionally untreated to be further formed by the moths. This again reconnects to the theme of multispecies co-creation, adding questions of how (and in what other domains) we can shape artifacts together with multiple non-human species.

3.4 Ethics

Similar to other RtD projects working in a multispecies context [5], there was no established procedure for ethical approval of the project in our institution. We, therefore, oriented ourselves on previous examples and tried-and-tested procedures such as animal-centered ethics [24] or the beneficiary-epistemology space [5]. As a result, we put together an interdisciplinary team with different expertise and backgrounds, including HCI, computing in apidology, beekeepers, and ethics board members, and re-visited ethical considerations before, during, and after our engagement with the bees. Following the welfare-centered ethics framework [24], we considered "that an animal is healthy and that they have what they want" (p. 226) and assumed mediated and contingent consent on an ongoing basis. Before the co-design engagement, we decided to work with specific colonies that were particularly strong and healthy. All interactions with the bees occurred in their familiar environment and with their beekeeper, so the beekeeper could compare the bees' behavior with their experience and could have stopped the project at any time if they had any concerns. The bees were not forced to participate but had the opportunity to visit and

Figure 4: Even curved combs (left) consist of perfectly even-shaped cell walls in nature. Candles and the wax helix we gave into the hive were shaped to abstract objects beyond recognition within weeks.

engage with the co-design space (or not) in any way they liked. As they had plenty of "normal" frames in the hive (Figure 1), their thriving as a colony did not depend on using the co-design space. We did not expect any unusual disturbance to the bees, considering that comb building is a typical bee activity, and we even supported the activity by providing wax objects to extrude so they did not have to sweat out much wax. One topic that triggered particularly strong discussions about ethics was monitoring. After thorough reflection, we decided to cause the least disturbance to bees and use an infrared camera (resulting in poorer image quality, see Figure 2) that was only running occasionally for short intervals to prevent heating up the hive.

Now, after the first season of co-designing with bees, we learned that the colony's queen survived the entire season. We interpret this as confirmatory evidence for the colony not being dissatisfied (for which they usually claim the queen and replace her). When interacting with bees (also in beekeeping), it is simpler to judge in retrospect whether an intervention benefited the colony but yet hard to tell how it impacts an individual bee. How can we achieve, e.g., mediated consent for individual animals when we can only judge the health of the entire colony? On existing participation ladders for mammals, insects can hardly exceed the rung of freedom [16, 17] and achieve a true understanding of the study purpose – so how can we cater for and categorize higher levels of participation in honeybees?

3.5 Natural vs Artificial Shapes

Naturally, bees build even, clean, thin comb with a precision that suffices standardized industrial production. The comb walls between cells meet at 120° angles and have an even thickness. A cell is about 10 mm long and starts out in a rounded shape which gets pressed into the familiar hexagonal pattern as bees keep working on them with heat and their body [20]. At the start, the wall consists of composites of lose wax flakes with a thickness of about 500 µm, but as the cell is built gets compressed into denser walls of around 90 µm. Only over time, as generations of bee larvae are bred, the silk cocoons that remain in the cell will add to the walls, reinforcing them to 250 µm after one year [42]. In contrast, the bees shaped complex irregular forms based on our given wax objects. These shapes may appear natural as they bring to mind the artistic craft expressions with natural materials common in Waldorf aesthetics (e.g., [38]). However, the abstract forms with their charming imperfections created by the bees are in so far artificial as bees would not build like that without the given starters. Evidence for this hypothesis can be found in the macro perspective and details of the resulting shapes: naturally, bees build straight combs. Even when forced by space constraints to bend their comb structure, the walls between cells are precise and evenly thin (Figure 4). In our project, convex objects animated bees to build walls of varying strength between cells, establish auxiliary dents instead of full cells, or even dig holes into the structure. How would bees react to different geometric forms? Would other bee species create different shapes?

4 Conclusion

In the first season of our project, unique artifacts originated from the co-creative activity between human and honeybee co-designers. Besides the artistic outcomes and material explorations, we found co-creation to be an adequate vehicle to investigate questions on relationships among and between species. When allowing for interactions exceeding agricultural utilization, the different lives of bees and humans inspire discussions on temporality and ethics.

Acknowledgments

We thank our six legged co-creators for their hard work and colleagues for their input as well as Renate Schubert for providing the picture of Figure 1, phase #1.

References

[1] Ilhan Aslan, Florian Primessnig, Martin Murer, Christiane Moser, and Manfred Tscheligi. 2013. Inspirations from honey bees: exploring movement measures for dynamic whole body gestures. In *Proceedings of the 2013 ACM International Conference on Interactive Tabletops and Surfaces* (St. Andrews, Scotland, United Kingdom) *(ITS '13)*. Association for Computing Machinery, New York, NY, USA, 421–424. https://doi.org/10.1145/2512349.2514919

[2] Fiona Bell, Latifa Al Naimi, Ella McQuaid, and Mirela Alistar. 2022. Designing with Alganyl. In *Proceedings of the Sixteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Daejeon, Republic of Korea) *(TEI '22)*. Association for Computing Machinery, New York, NY, USA, Article 2, 14 pages. https://doi.org/10.1145/3490149.3501308

[3] Fiona Bell, Derrek Chow, Hyelin Choi, and Mirela Alistar. 2023. Scoby Breastplate: Slowly Growing a Microbial Interface. In *Proceedings of the Seventeenth International Conference on Tangible, Embedded, and Embodied Interaction* (Warsaw, Poland) *(TEI '23)*. Association for Computing Machinery, New York, NY, USA, Article 34, 15 pages. https://doi.org/10.1145/3569009.3572805

[4] Fiona Bell, Joshua Coffie, and Mirela Alistar. 2024. Bio-Digital Calendar: Attuning to Nonhuman Temporalities for Multispecies Understanding. In *Proceedings of the Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Cork, Ireland) *(TEI '24)*. Association for Computing Machinery, New York, NY, USA, Article 38, 15 pages. https://doi.org/10.1145/3623509.3633386

[5] Steven David Benford, Clara Mancini, Alan Chamberlain, Eike Schneiders, Simon D Castle-Green, Joel E Fischer, Ayse Kucukyilmaz, Guido Salimbeni, Victor Zhi Heung Ngo, Pepita Barnard, Matt Adams, Nick Tandavanitj, and Ju Row Farr. 2024. Charting Ethical Tensions in Multispecies Technology Research through Beneficiary-Epistemology Space. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 626, 15 pages. https://doi.org/10.1145/3613904.3641994

[6] Gary J. Blomquist, Arthur J. Chu, and Stephen Remaley. 1980. Biosynthesis of wax in the honeybee, Apis mellifera L. *Insect Biochemistry* 10, 3 (1980), 313–321. https://doi.org/10.1016/0020-1790(80)90026-8

[7] Parzival Borlinghaus, Jörg Marvin Gülzow, and Richard Odemer. 2024. In-hive flatbed scanners for non-destructive, long-term monitoring of honey bee brood, pathogens and pests. *Smart Agricultural Technology* 9 (2024), 100655. https://doi.org/10.1016/j.atech.2024.100655

[8] Parzival Borlinghaus, Jakob Jung, and Richard Odemer. 2023. Introducing Pollenyzer: An app for automatic determination of colour diversity for corbicular pollen loads. *Smart Agricultural Technology* 5 (2023), 100263. https://doi.org/10.1016/j.atech.2023.100263

[9] Parzival Borlinghaus, Richard Odemer, Frederic Tausch, Katharina Schmidt, and Oliver Grothe. 2022. Honey bee counter evaluation – Introducing a novel protocol for measuring daily loss accuracy. *Computers and Electronics in Agriculture* 197 (2022), 106957. https://doi.org/10.1016/j.compag.2022.106957

[10] Zoë Breed, Peter van der Putten, and Bahareh Barati. 2024. Algae Alight: Exploring the Potential of Bioluminescence through Bio-kinetic Pixels. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference* (Copenhagen, Denmark) *(DIS '24)*. Association for Computing Machinery, New York, NY, USA, 1412–1425. https://doi.org/10.1145/3643834.3660728

[11] Rachel Carson. 1962. *Silent Spring*. Houghton Mifflin, Boston, Massachusetts, USA.

[12] Dominique Chen, Young ah Seong, Hiraku Ogura, Yuto Mitani, Naoto Sekiya, and Kiichi Moriya. 2021. Nukabot: Design of Care for Human-Microbe Relationships. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI EA '21)*. Association for Computing Machinery, New York, NY, USA, Article 291, 7 pages. https://doi.org/10.1145/3411763.3451605

[13] Lars Chittka. 2022. *The Mind of a Bee.* Princeton University Press, Princeton. https://doi.org/10.1515/9780691236247

[14] Tanja Döring. 2016. The Interaction Material Profile: Understanding and Inspiring How Physical Materials Shape Interaction. In *Proceedings of the 2016 CHI Conference Extended Abstracts on Human Factors in Computing Systems (CHI EA '16)*. Association for Computing Machinery, New York, NY, USA, 2446–2453. https://doi.org/10.1145/2851581.2892516

[15] R.M. Goodwin, Michelle Taylor, H. McBrydie, and H.M. Cox. 2006. Drift of Varroa destructor-infested worker honey bees to neighbouring colonies. *Journal of Apicultural Research* 45 (2006), 155–156. https://doi.org/10.1080/00218839.2006.11101335

[16] Roger Hart. 1992. Children's participation from tokenism to citizenship. 1992. *Florence, UNICEF Innocenti Research Centre* 66 (1992), 39 pages.

[17] Ilyena Hirskyj-Douglas, Janet C Read, and Brendan Cassidy. 2015. Doggy ladder of participation. In *Workshop on Animal-Computer Interaction, British HCI*, Vol. 15. Association for Computing Machinery, New York, NY, USA, 4 pages.

[18] Yuta Ikeya, Miguel Bruns, and Bahareh Barati. 2024. Designing for Interdependence of Bees, Garden, Designer, and the Changing Season. In *Proceedings of the 2024 ACM Designing Interactive Systems Conference* (Copenhagen, Denmark) *(DIS '24)*. Association for Computing Machinery, New York, NY, USA, 1385–1399. https://doi.org/10.1145/3643834.3660743

[19] Sylvia Janicki, Alexandra Teixeira Riggs, Noura Howell, Anne Sullivan, and Nassim Parvin. 2024. Sensing Bodies: Engaging Postcolonial Histories through More-than-Human Interactions. In *Proceedings of the Eighteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Cork, Ireland) *(TEI '24)*. Association for Computing Machinery, New York, NY, USA, Article 41, 15 pages. https://doi.org/10.1145/3623509.3633389

[20] B. L. Karihaloo, K. Zhang, and J. Wang. 2013. Honeybee combs: how the circular cells transform into rounded hexagons. *Journal of The Royal Society Interface* 10, 86 (2013), 20130299. https://doi.org/10.1098/rsif.2013.0299

[21] Tomas Libertiny. 2022. Eternity (a.k.a. Nefertiti). http://www.tomaslibertiny.com/sculptures#/eternityredyellow/ Accessed October 10, 2024.

[22] Ann Light, Alison Powell, and Irina Shklovski. 2017. Design for Existential Crisis in the Anthropocene Age. In *Proceedings of the 8th International Conference on Communities and Technologies* (Troyes, France) *(C&T '17)*. Association for Computing Machinery, New York, NY, USA, 270–279. https://doi.org/10.1145/3083671.3083688

[23] Clara Mancini. 2011. Animal-computer interaction: a manifesto. *Interactions* 18, 4 (July 2011), 69–73. https://doi.org/10.1145/1978822.1978836

[24] Clara Mancini. 2017. Towards an animal-centred ethics for Animal–Computer Interaction. *International Journal of Human-Computer Studies* 98 (2017), 221–233. https://doi.org/10.1016/j.ijhcs.2016.04.008

[25] Clara Mancini, Shaun Lawson, and Oskar Juhlin. 2017. Animal-Computer Interaction: The emergence of a discipline. *International Journal of Human-Computer Studies* 98 (2017), 129–134. https://doi.org/10.1016/j.ijhcs.2016.10.003

[26] Clara Mancini and Jussi Lehtonen. 2018. The Emerging Nature of Participation in Multispecies Interaction Design. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) *(DIS '18)*. Association for Computing Machinery, New York, NY, USA, 907–918. https://doi.org/10.1145/3196709.3196785

[27] Netta Ofer and Mirela Alistar. 2023. Felt Experiences with Kombucha Scoby: Exploring First-person Perspectives with Living Matter. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 477, 18 pages. https://doi.org/10.1145/3544548.3581276

[28] Pat Pataranutaporn, Angela Vujic, David S. Kong, Pattie Maes, and Misha Sra. 2020. Living Bits: Opportunities and Challenges for Integrating Living Microorganisms in Human-Computer Interaction. In *Proceedings of the Augmented Humans International Conference* (Kaiserslautern, Germany) *(AHs '20)*. Association for Computing Machinery, New York, NY, USA, Article 30, 12 pages. https://doi.org/10.1145/3384657.3384783

[29] Bernard Picart. 1738. Ruche dessinée d'après nature dans le Jardin de Medecine d'Amsterdam [Life-drawing of a beehive in the Amsterdam Medical Garden]. Xylograph.

[30] Isabel P. S. Qamar, Rainer Groh, David Holman, and Anne Roudaut. 2018. HCI meets Material Science: A Literature Review of Morphing Materials for the Design of Shape-Changing Interfaces. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems* (Montreal QC, Canada) *(CHI '18)*. Association for Computing Machinery, New York, NY, USA, 1–23. https://doi.org/10.1145/3173574.3173948

[31] Etienne Rabaud. 1937. *Phénomène social et société animale [Social phenomena and animal society]*. F. Alcan, Paris, France. 115–117 pages.

[32] Eike Schneiders, Steve Benford, Alan Chamberlain, Clara Mancini, Simon Castle-Green, Victor Ngo, Ju Row Farr, Matt Adams, Nick Tandavanitj, and Joel Fischer. 2024. Designing Multispecies Worlds for Robots, Cats, and Humans. In *Proceedings of the CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 593, 16 pages. https://doi.org/10.1145/3613904.3642115

[33] Nancy Smith. 2022. Smart Bee Houses: Designing to Support Urban Pollination. In *Proceedings of the Eight International Conference on Animal-Computer Interaction* (Bloomington, IN, USA) *(ACI '21)*. Association for Computing Machinery, New York, NY, USA, Article 9, 6 pages. https://doi.org/10.1145/3493842.3493894

[34] Marie Louise Juul Søndergaard and Nadia Campo Woytuk. 2023. Feminist Posthumanist Design of Menstrual Care for More-than-Human Bodies. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, 1–18. https://doi.org/10.1145/3544548.3581083

[35] Jürgen Tautz. 2022. *How Research on Honeybee Communication Began.* Springer International Publishing, Cham, 9–20. https://doi.org/10.1007/978-3-030-99484-6_2

[36] Guy Theraulaz and Eric Bonabeau. 1999. A Brief History of Stigmergy. *Artificial Life* 5, 2 (1999), 97–116. https://doi.org/10.1162/106454699568700

[37] Karl von Frisch. 1953. *Aus dem Leben der Bienen [The Life of Bees]*. Springer, Cham. https://doi.org/10.1007/978-3-642-61235-0

[38] Johannes Wagemann and Sarah Starosky. 2025. Aesthetic Production in Clay Molding: Mental and Dynamically Embodied Action Mediate Between Formal and Material Aspects of Experience. *Empirical Studies of the Arts* 43, 1 (2025), 153–187. https://doi.org/10.1177/02762374241255875

[39] Ron Wakkary. 2021. *Things we could design: For more than human-centered worlds*. MIT press, Cambridge, Massachusetts, USA.

[40] Ron Wakkary, Doenja Oogjes, Nazmus Sakib, and Armi Behzad. 2023. Turner Boxes and Bees: From Ambivalence to Diffraction. In *Proceedings of the 2023 ACM Designing Interactive Systems Conference* (Pittsburgh, PA, USA) *(DIS '23)*. Association for Computing Machinery, New York, NY, USA, 790–807. https://doi.org/10.1145/3563657.3596081

[41] Michelle Westerlaken and Stefano Gualeni. 2016. Becoming with: towards the inclusion of animals as participants in design processes. In *Proceedings of the Third International Conference on Animal-Computer Interaction* (Milton Keynes, United Kingdom) *(ACI '16)*. Association for Computing Machinery, New York, NY, USA, Article 1, 10 pages. https://doi.org/10.1145/2995257.2995392

[42] Kai Zhang, Huiling Duan, Bhushan L. Karihaloo, and Jianxiang Wang. 2010. Hierarchical, multilayered cell walls reinforced by recycled silk cocoons enhance the structural integrity of honeybee combs. *Proceedings of the National Academy of Sciences* 107, 21 (2010), 9502–9506. https://doi.org/10.1073/pnas.0912066107

[43] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (San Jose, California, USA) *(CHI '07)*. Association for Computing Machinery, New York, NY, USA, 493–502. https://doi.org/10.1145/1240624.1240704