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Hive: biomimesis, interactive art, and the honeybee

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HIVE: BIOMIMESIS, INTERACTIVE ART, AND THE HONEYBEE

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HIVE – BIOMIMESIS, INTERACTIVE ART, AND THE HONEYBEE

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Dedication

In dedication to Richard Michaud and Gavin Weddell whom both encouraged my academic interests.

Abstract

The pressing need for sustainable design solutions in the face of numerous environmental concerns has led to increased awareness of the importance in acknowledging and respecting older and present day sentient beings, as we can learn much from their anatomy and behaviours. An understanding of the need to explore the complex characteristics which enabled different species to flourish has led designers to turn to biomimesis—borrowing from nature largely for human benifit—as a way to create more sustainable human environment. Biomimesis's advantages can be reciprocal between human and non-human, but is not always the case. While my paper doesn't explicitly try to solve sustainability issues using biomimesis, it does discuss how mimicking organisms can create new types of art and design. Artists can use biomimesis to further investigate nature and produce works offering new perspectives that we are not readily accustomed to and challenge or question our human landscape.

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Acknowledgements

I would like to mention those that helped make *Hive* become a reality. First I would like to express appreciation to my supervisor Dr. Dana Cooley whose direction and guidance were indispensable for helping me formulate this research and interactive installation. I would also like to thank my supervisory committee, Leanne Elias, Dr. Jackson Leween, and Carl Spence who took the time to evaluate my work and offer valuable feedback, and Dr. Aaron Taylor for moderating my final defense. Many people stepped up and volunteered their time to help me with the creation of *Hive*: Joshua Gordon, Autumn Read, Tyler Heaton, Mary-Anne McTrowe, Brent Coulton, Niall Donaghy, Kevin Sehn, Bernard Spaini, my brother Clifford, and parents Duane and Pamela. My final acknowledgement is to the staff and students of the New Media department at the University of Lethbridge who encouraged me over my graduate and undergraduate career.

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1.1 Introduction to Biomimesis

Life on Earth began an estimated 3.8 billion years ago and over the course of this timespan diverse organisms have adapted to the many hardships of inhabiting this planet. While some organisms met with extinction, others proved to be adept at surviving, evolving their bodies and behaviours to cope with Earth's varied and changing environment. This evolution has resulted in numerous species, each having its own set of unique traits. In contrast, humans and their reliance on technology as a means for survival have only existed a fraction of the time life has existed and organically evolved on this planet. Primitive human tools made from sharpened rock date back only 2.6 million years, a timeline of technology that has a sense of hastiness when compared to organic evolution.[1] Humans are also not the only creatures to have fashioned tools, as numerous animals use them in various ways for survival (New Caledonian crows use Pandanus leaves to extract grubs from holes for example). Therefore, we are not so unique in creating implements for our species longevity, and the phylogenetic record of tool use left by some extinct hominids could help us in better understand human evolution.[2]

With the pressing need to find sustainable solutions for reducing human impact on the environment an increasing number of scientists, environmentalists, philosophers, and artists are asking, "Would it not make sense to consider borrowing from other beings some of these evolutionary survival traits which have existed for billions of years?" The longevity of these attributes suggests they are not randomly assigned biology and

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[1] "Stone Tools." Smithsonian: National Museum of Natural History, accessed June 26, 2018, http://humanorigins.si.edu/evidence/behavior/stone-tools.

[2] Amanda Seed and Richard Byrne, "Animal Tool-Use," *Current Biology* 20 no.23 (December 2010): 1038, accessed July 12, 2018, https://doi.org/10.1016/j.cub.2010.09.042.

purposeful for an organism's perseverance in nature, so reproducing was has come from evolution has useful merit. By studying these evolutionary traits we can creating designs that have the intent of environmental sustainability, problem solving, and/or improving an existing creation. The Anthropocene Era ("Anthropo" meaning human and "cene" meaning new) is defined as a period in time where the human effects on the environment have reached levels severe enough to outweigh natural changes.[3] Scientists Eugene Stoermer and Paul Crutzen argue that traces of the Anthropocene Era began during the global industrial expansion of the early 1850s when the planet underwent an increase in greenhouse gases, land-use changed from the increase in large-scale development of natural habitat, rapid population growth, and the burning/refining of fossil fuels.[4] The consequences of this human activity is argued to be responsible for the beginning of global climate change, extinction of various species, and other numerous irreversible damages to the environment. The chemical makeup of modern plastics, for example, takes thousands of years to fully decompose, resulting in a buildup of toxic material in the environment. In particular, waterways are most susceptible to this waste as waves and currents break plastics apart which causes them to release chemicals that, along with the particles of material, are potentially lethal to aquatic organisms. One way scientists are mitigating this dilemma is through the replication of biological traits that could allow for new plastics to decay much faster than their petroleum-derived counterparts. Bioplastics composed of renewable and non-petroleum-based organic compounds (corn and

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[3] Willam F. Ruddiman, "The Anthropocene," *Annual Review of Earth and Planetary Sciences* 41 (February 2013): 46, accessed April 29, 2018, https://doi.org/10.1146/annurev-earth-050212-123944.
[4] Willam F. Ruddiman, "The Anthropocene," *Annual Review of Earth and Planetary Sciences* 41 (February 2013): 46, accessed April 29, 2018, https://doi.org/10.1146/annurev-earth-050212-123944.

microbiota, for example) are being tested as a potential way to reduce waste, as the biochemical features of these plastics can be engineered to biodegrade, and, in some cases, be compostable. Scientists are also experimenting with genetically modified plastic-eating enzymes which would considerably hasten the decomposition of plastics.[5]

Biomimesis is the practice of humans adapting or imitating an organism's characteristics or traits in order to take advantage of these features for human designs. As population growth has accelerated over the turn of the twenty-first century, humans are searching for sustainable ways of creating on a planet with a fragile ecosystem containing limited resources. With an increased awareness of the need to find solutions to pressing environmental concerns, the biomimetic model of copying what "works" in nature has increasingly become a viable and important alternative to traditional methods of design and construction. It is important to note, however, that not all gestures with respect to environmental concern and future sustainability have acknowledged or respected non-human entities despite highlighting their qualities. While the notion of integrating nature's qualities into facets of human design may seem far-fetched to some, it has in fact been around for decades. Velcro, for instance, was invented in 1945 by George de Mestral after he observed the hook-like structure of burdock seeds which tenaciously clung to fabric and hair (Fig.1).[6]

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[5] "Plastic-eating enzyme could help fight pollution, scientists say," CBC Technology and Science, last modified April 17, 2018, accessed April 24, 2018, http://www.cbc.ca/news/technology/plastic-eating-enzyme-pollution-1.4622923.

[6] *The Hutchinson Unabridged Encyclopedia with Atlas and Weather Guide*, s.v. "Velcro," accessed April 22, 2018, http://ezproxy.uleth.ca/login?url=https://search.credoreference.com/content/entry/heliconhe/velcro/0?institutionId=2649.

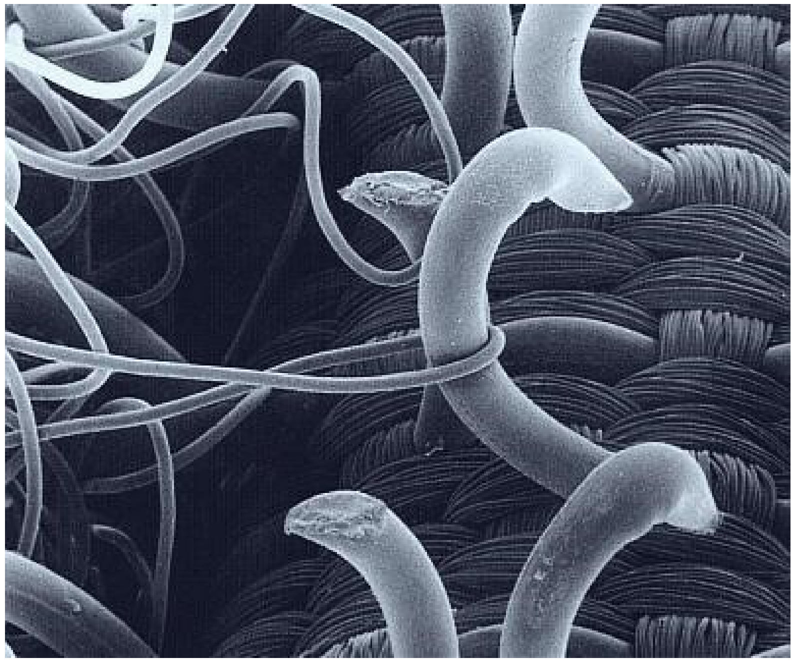

Fig. 1: Velcro under a microscope.

This cross-species method for designing attracts me as it permits the blending of my background in beekeeping and practice as an interaction designer. Working with honeybees has allowed me to observe their behaviours and habits, and the research I cover in this paper, along with designing my project has helped me to further understand them from a non-human perspective through the sensorial traits I have chosen to work with. I have better come to realize how evolved the honeybee's behaviours and anatomy are, characteristics which I had previously erroneously assumed to be the by-product of centuries of human domestication. My research and body of work addresses the unique traits of the honeybee and explores some implications of biomimesis in art & design.

Hive is comprised of forty plywood “clusters.” Each cluster is made up of three plywood hexagons (13.0 cm x 14.8 cm x 13.3 cm) that have semi-transparent faces and houses the electronic components, including an Arduino Uno, which regulates the interactive behavior of the installation. Each triumvirate contains sensors which react to other clusters, as well as a participant's handling of a cluster. For example, rotating a cluster will cause an RGB LED to cycle through the rainbow of colours; bringing two clusters into contact will trigger sound. Magnets on the back of the clusters let participants position these on steel wall, essentially constructing honeycombs.[7] The steel wall acts like a beeswax frame (discussed in more detail in a further section) that allows participants to build their own honeycomb designs similar to how a bee does. As the name of the installation implies, *Hive* steals from the honeybee both in terms of the construction of the installation and as well the behaviour it seeks to elicit from participants. *Hive* has two purposes: firstly, to find ways to use the characteristics of a honeybee and it's honeycombs as an artistic medium and secondly to provide participants with simple and easy-to-understand forms that, when arranged in a pattern, transform an indoor space into a metaphorical recreation of a honeybee's sensorium giving us a glimpse of the world from a bee's perspective. During exhibition *Hive* was able to achieve this, but the ease of manipulating clusters made the work more of a creative tool that allowed participants to create their own contexts of the work outside of the intended theme of biomimesis. Essentially, *Hive's* clusters acted like a paintbrush or pixels that participants can use to create art using a system based on organic traits I have researched. I discuss these findings in the conclusion of this paper.

[7] In Sections 4 and 5 I further elucidate my design choices and iteration process.

2.1 Brief History of Biological Fascination

While contemporary employment of biomimesis largely focuses on issues of sustainable designs, the interest in using biomimesis during the nineteenth century was more a cultural phenomenon than sustainability issue, which is visible in many forms of media produced at the time that explored the fascinations of the natural sciences. As a beekeeper (if only on a small-scale) I am particularly interested in the surge of attraction to entomology during the 1800s and as a designer I'm interested in studying how I can create a work that pays homage to the cultural appeal of insects in that period. Specifically, my research focuses on copying chosen traits of the honeybee because of my apiary endeavours and I exploit them in a similar fashion to the examples I discuss below which, in various ways, concern themselves with investigating the human/non-human relationship.

The popularity of entomology in the nineteenth century can, in part, be explained by the advancements in the quality of microscopes. Improvements in the lens quality of these optical devices meant that for the first time it was possible to see the minutia of an insect's anatomy more clearly. These alien structures gave rise to numerous theories as to how these "anomalies" came to exist. In their book *Introduction to Entomology* (1826), for example, naturalists William Kirby and William Spence hypothesize that insects are the microcosmical doubling of plants and animals. Kirby and Spence argue that the mimesis that exists between living things are nature's way of picking a reoccurring trait that will benefit an array of species. For example, Kirby and Spence note that similar form, substance, and vascular structure present in an insect's wings and a tree's leaves is evidence that all organisms are connected in some way.[8] Another naturalist at this time, James Rennie, drew on theological language and human development to describe the behaviours of insects. Rennie, for instance, compares the work of a carpenter bee to human artisans to prove the superior and almost miraculous way in which a bee perfects habitation without the practice or tools of the skilled human.[9] Further, in Rennie's estimation, the hives bees construct act as "miniature cities," foreshadowing the industrial urbanization that exploded in the nineteenth century.[10] While humans have used precision engineering to construct impressive edifices for eons (the pyramids of ancient Egypt, Roman roads and aqueducts, Medieval cathedrals, and Victorian palaces for example), this meticulous human construction was viewed by Rennie to pale in comparison to the precision, audacity, and vastness of natural counterparts.[11]

This treatment of mimesis between natural occurrences and human behaviour was particularly popular among writers and artists in the nineteenth century as new scientific discoveries, enabled by improved optical devices, sparked their imagination to create works that pull the viewer/reader into a non-human perspective. To cite a popular instance, Lewis Carroll's 1865 novel *Alice's Adventures in Wonderland* uses mimesis by physically shrinking the main character to the size of an insect. Carroll lets the reader experience an uncharted, but naturally relatable, wonderland through the eyes of Alice, a young girl that happened to discover this mysterious world upon falling down a rabbit hole. As she explores the various landscapes that exist in the wonderland Alice goes

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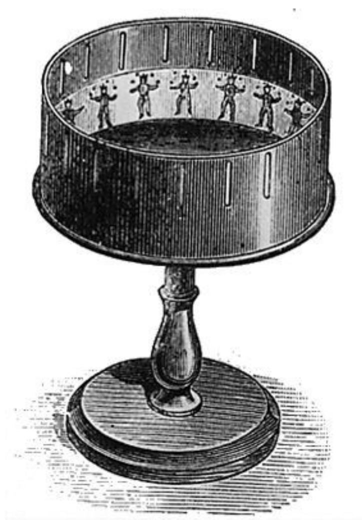
[8] Jussi Pakka, *Insect Media: An Archaeology of Animals and Technology,* (University of Minnesota Press, 2010), 3-4.
[9] Ibid, 37.
[10] Ibid.
[11] Ibid.

through many physical transformations in scale, at times mimicking the size of various anthropomorphized animals. Alice clashes with the alien qualities of the wonderland whose underlying characteristic is that of metamorphosis: transformation, development, and change.[12] In stark contrast to Alice's inability to comprehend the metaphysics of wonderland, the character of the caterpillar is much more inclined to accept change as its own existence is defined by the metamorphosis between physical stages (caterpillar, cocoon, and butterfly). In *Wonderland* a myriad of creatures challenge Alice's normative human-centric point of view as she explores her metaphysical environment; she, and by extension the reader, has to aesthetically negotiate absurdity, astonishment, and scientific analysis. In doing so, Carroll constructs an influential commentary on the relationship between scientific reasoning and fantastical imagining, asking us to wonder at the natural world and all its peculiarities.[13]

Etienne-Jules Marey's experiments during the nineteenth century also explore the parallels of scientific reasoning and fantastical imagining, but in this case comparing animals to machines. Marey observes and collects data from a multitude of organisms which he then uses to create machines that synthetically mimic the organism's movement and perception.[14] Pre-cinematic devices such as the Zoetrope and Phenakistoscope served as inspiration for Marey's data collection devices.[15] On the Zoetrope's cylinder or Phenakistoscope's disk (Fig.2), graphics are illustrated that describe a moving figure

[12] Ibid, 85.
[13] Melanie Keene, *Science in Wonderland: The Scientific Fairy Tales of Victorian Britain* (Oxford University Press, 2015), 105.
[14] Jussi Parikka, *Insect Media: An Archaeology of Animals and Technology,* (University of Minnesota Press, 2010), 12.
[15] Marta Braun and Etinne-Jules Marey, *Picturing Time: The Work of Etienne-Jules Marey (1830-1904),* (University of Chicago Press, 1992), 30.

using a sequence of stills. When these gadgets are spun, the succession of the images seemingly blurs together and simulates the illusion of movement, an effect known as persistence of vision. Marey developed his own way of graphically capturing the motion of anatomy (arms, legs, wings) that is unrecognizable to the human eye due to its speed.



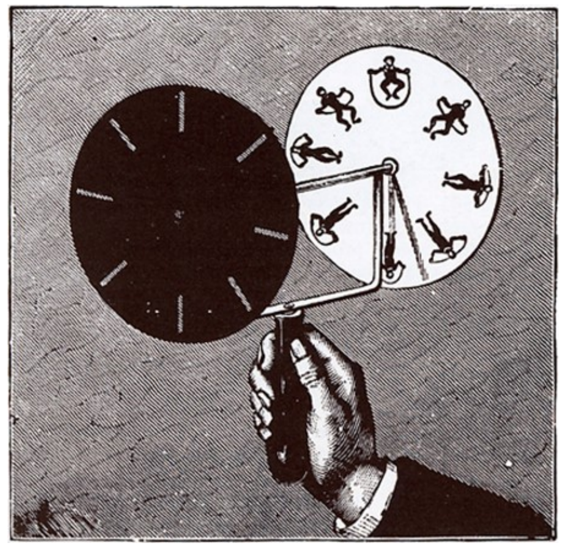


Fig. 2: Zoetrope (left) and Phenakistoscope (right).

Attaching sensors of his own devising to animals, Marey was able to record the animal's movement. One such invention captured the movement of a wasp's wing using a reworked version of Hermann von Helmhotz's myograph (a medical device used to measure and record the contractions of muscles in graphical form).[16] Marey would harness a wasp by its abdomen using a set of forceps and then place the creature's wing in direct contact with a sheet of blackened paper moving along a cylinder.[17] As the wing moved, it brushed away the soot leaving an impression, an abstract representation of the wing's movement (Fig 3.). However, this method is not accurate enough in graphically

[16] Parikka, *Insect Media: An Archaeology of Animals and Technology, 1*3.
[17] Braun and Marey, Picturing Time: The Work of Etienne-Jules Marey (1830-1904), 31.

capturing the exact motion of the wasp's wing as the wing would slow down from resistance exerted by contacting the cylinder. To compensate for this interference Marey gilded the tip of the wing and projected a ray of sunlight onto it causing a luminous figure-eight to be traced (Fig. 4). Marey then used the data he collected from this test to build a new machine which attempted to accurately mimic the motions of a wasp's wing (Fig.5). Iterations of new tests and machines would run through the course of Marey's scientific career, and include motion studied of pigeons, frogs, cats, horses, and nude soldiers to name a few. The treatment of his subjects during these test are regarded as being quite unethical, however, where the study of the motor functions of the creature Marey worked with was, for him, more important than respecting its wellbeing (gilding the wasps wings permanently disfigures the insect for the purpose of science). Marey's works, while scientific in nature, had a seminal influence on early twentieth century abstract art, despite that reception not being his intention.[18] The modernist art movement, brought on by changes in technology and culture of the time, resulted in artists exploring ways to create new modes of thinking about experiencing time and space.[19] The various

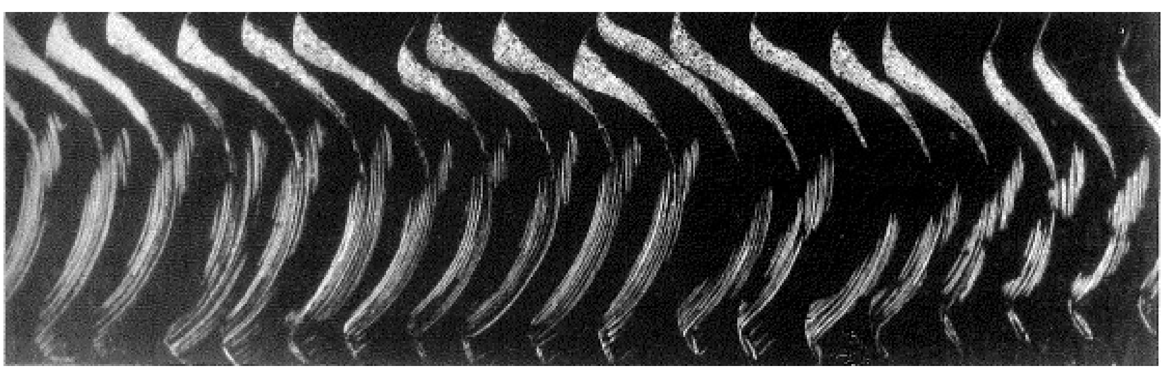


Fig. 3: Tracings of the movement of a wasps wings.

[18] Ibid, 277.
[19] Ibid, 264.

machines built by Marey now became devices that artists could employ to explore creating works that give viewers an unfamiliar way of experiencing time. After Marey's death, artists like Marcel Duchamp and Giacomo Balla began creating adaptations of the

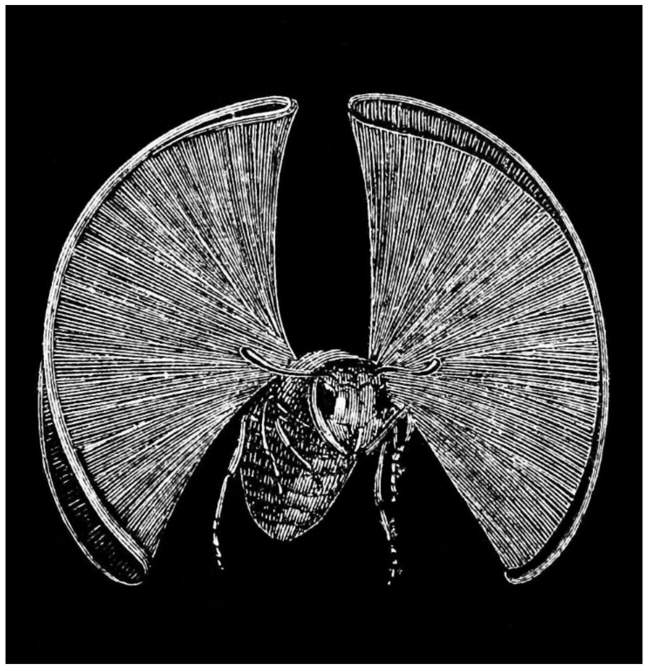


Fig. 4: Illustration of observed wasps wings motion.

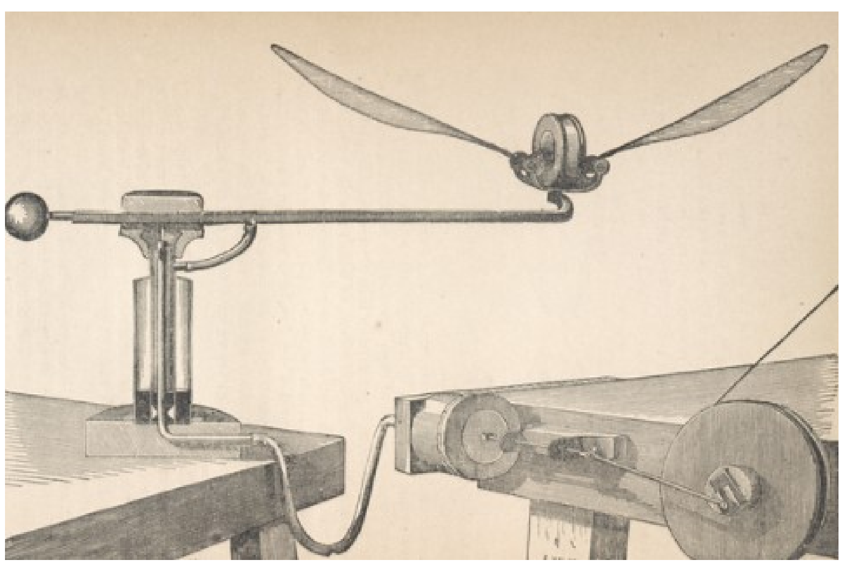


Fig. 5: Marey's insect machine

rhythmical patterns exhibited by his works, using time as both a scientific and artistic investigation.[20]

Hive is less an exploration of capturing time and more an experiment in creating a device that aggregates a creature's characteristics, similar to the instruments Marey built for recreating his animal subject's anatomy. His insect machine, for example, exploits and reproduces the moving characteristics of an insect to produce a new way of looking at the creature (the slowing of an insect's wing to better see its path to recreate its motion). *Hive* does the same, using honeybee traits (vision, swarming, honeycombs) to create a device that produces a new way for us to imagine the creature's world. Participants of *Hive* often worked together in groups (similar to how honeybees work together) to collectively transform an expression they think up (cultural reference, abstract shapes, symbols, for example) using the clusters. The ideas that they conceive re effectively altered and reshaped by the multiple aesthetic conventions (shapes, colours, locations, and sounds of clusters for example) that *Hive's* honeybee-inspired design offers. The result of interacting with *Hive* thus allows participants this glimpse into the honeybees' world, similar in manner to what Marey's works, like insect machine, were able to achieve in creating a human-made representation of an observation of a specific creature.

[20] Ibid, 277.

3.1 Examples of Biomimesis in Contemporary Art and Design

Recent studies in biomimesis, along with previous insights and research, have made us more aware of the interdependency between humans and nature, driving the need for sustainable practices of human development in a world facing numerous challenges regarding resource consumption, pollution, and impoverishment over the last century. My research, while having overlap with some areas of sustainable practice, focuses more on the implications of biomimesis as a creative tool that can extend conventional human-centered methods for the production of art and design.

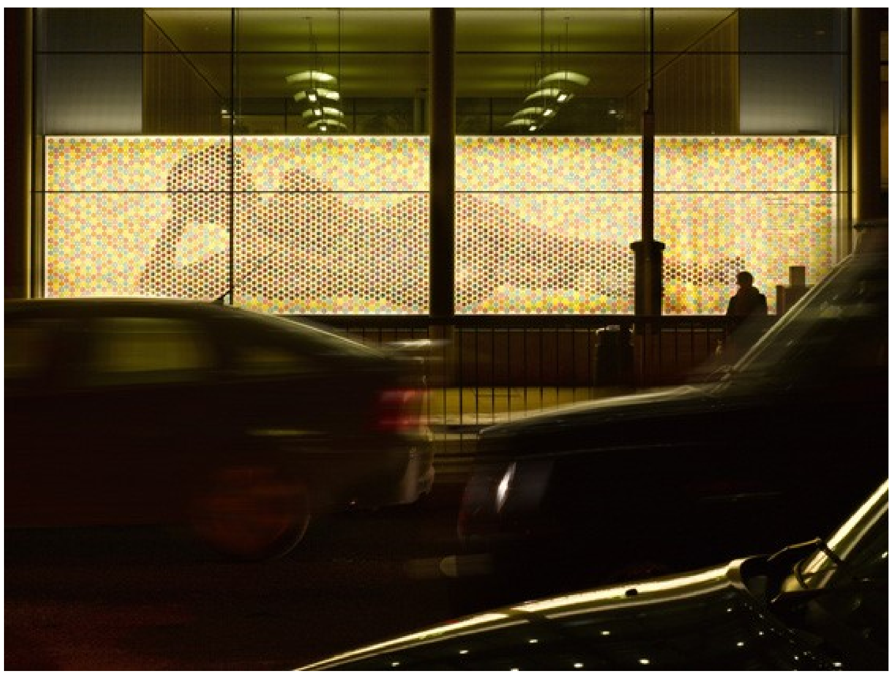


Fig. 6: *Co-Existence (2009)*

Innovations in microbiology have allowed artists and designers to experiment with microorganisms as a medium. Designer Julia Lohmann, for example, uses microorganisms in her work *Co-Existence* (Fig. 6) to draw attention to the symbiotic relationships that exist between humans and bacteria. Assisted by microbiologist Michael

Wilson, Lohmann photographs numerous species of laboratory grown bacteria that exist within our bodies. These photographs are superimposed onto transparent coloured circles that are then placed into the petri dishes, totalling nine thousand in number. Lohmann arranges the dishes in a grid pattern that corresponds to where each bacteria species would exist in a female body (Fig. 7). The mass of these dishes creates the silhouette of a nude female figure when viewed from a distance. Lohmann chooses to work with the female figure for two reasons: the first being that females host a greater variety of microorganisms than men, which means that by working with the female body Lohmann has a greater diversity of bacteria to work with.[21] Secondly, the medium she works with (microorganisms) has negative connotations of contagion and disease, but through her aesthetic treatment, seems more alluring when viewed from afar, becoming just as appealing as the female figure who is revered in art history for its beauty; up-close we are

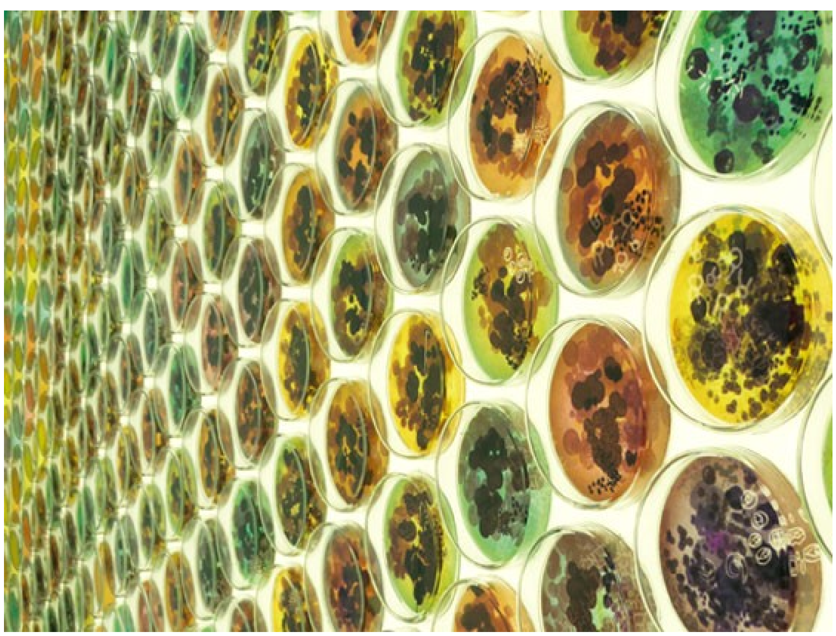


Fig. 7: Grid of petri dishes used in *Co-Existence.*

[21] Bio-Design, 218.

aware of the medium (bacteria) but from a distance the photographic images blur and the viewer becomes more focused on the subject (nude female) the medium is comprised of. *Co-existence* underlies the recent realization that the human body is a hybrid of human and bacterial cells, where nine in ten cells are of the latter.[22] This relationship of human and bacterial cells coexisting within our bodies is symbiotic: digestion and the immune system rely on both types of cells to allow us to properly function, a relationship that literally borrows an organism (like biomimesis) for both its own and human-hosts gain.

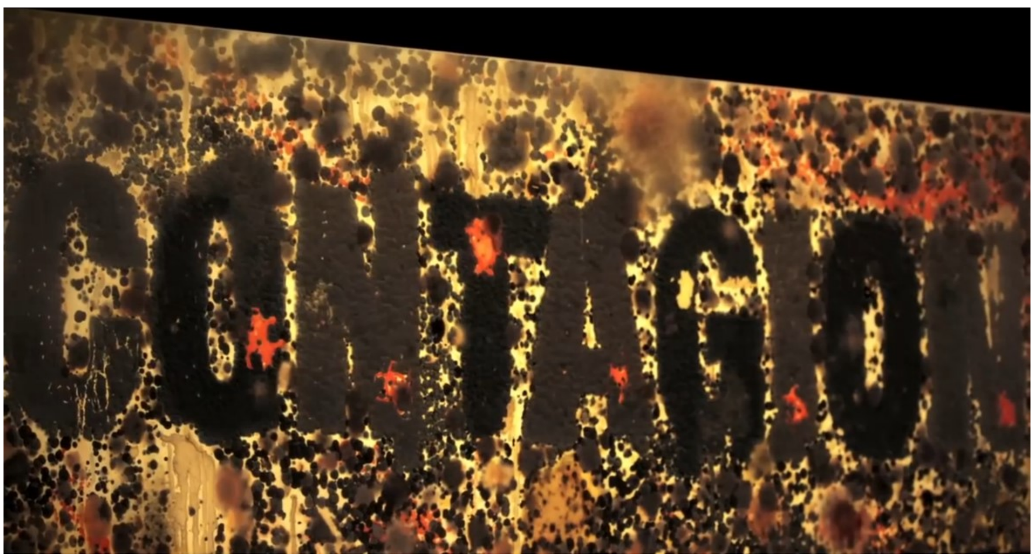


Fig. 8: *Contagion (2011)*

While *Co-Existence* references through photography the bacteria used (a representation of the organisms), other works incorporate the live/actual microorganisms into their design. One such example is the promotional billboards for Steven Soderburgh's 2011 film *Contagion,* which use Penicillium fungus and Serratia marcescens bacteria to spell out the film's logo on two large petri dishes (Fig. 8).[23] Once coated, the petri dishes were installed at an abandoned storefront in Toronto and the microorganisms were left to grow

[22] Myers, *Bio-design: Nature + Science + Creativity,* 218.
[23] Ibid, 147.

over six days. The plot of *Contagion* revolves around panic arising from the discovery of a potential pandemic that threatens humankind. This theme of panic is literally inscribed in the billboards, where biohazardous organisms instill anxiety in passersby. A film crew recorded pedestrian reactions, who direct their disgust towards the mass of bacteria and fungus that are contained behind a seemingly fragile glass casing. [24]

The designs of Jelte van Abbema's *Symbiosis* are a less vexing example of using microbials for graphic design. In *Symbiosis,* Abbema experiments with using print methods in combination with cultured bacterial as an alternative to inks and dyes of traditional print media to generate graphics.[25] Abbema uses methods of print-screening and moveable type with wood-cut letters to stamp Escherichia coli bacteria onto the growth medium contained in a petri dish. The bacteria then grows into the letters, changing in colour and appearance with response to the environment over serval days and eventually dying. One large-scale work Abbema publicly exhibits is a huge letter 'A' grown inside an environmentally controlled poster-box/petri dish for growing microbial cultures (Fig. 9). Along with creating an environmentally sustainable material for print media, Abbema is indirectly exploring the ephemerality of natural materials whose lifespan are dwarfed by synthetic inks and dyes. This dynamic existence of a microorganism allows artists and designers to potentially create works whose contexts can change with ebbs and flows of the physical changes an organism goes through to reach maturity. However, this ephemerality also limits the use of microorganism as a

[24] Glen D'Souza, "Contagion 'Bacteria Billboard'," Vimeo video, 1:39, April 27, 2012, https://vimeo.com/74666194.
[25] Ibid,142.

material, as using something that simply dies after a few days can be difficult to manage when designing works meant to last long durations.

Fig. 9: *Symbiosis (2009)*-Eindhoven, Netherlands

Bioluminescence (chemical compounds that allow a creature to generate light) is another trait being investigated by artists. The *Half Life Lamp* (Fig. 10) created by Joris Laarman at the Faculty of Tissue Regeneration at the University of Twente in the Netherlands, is a bioluminescent lamp that runs on genetically modified cells extracted from Chinese hamster ovaries. These cells are enhanced by the introduction of a firefly's luciferase gene (which produces the bioluminescent enzyme luciferase), and then applied and grown on biopolymer sheets that act as a lampshade.[26] The lamp is then placed in a vessel

[26] "Half Life Lamp (2010)." Works, accessed April 19, 2018, http://www.jorislaarman.com/work/half-life/.

designed to circulate liquid nutrients needed for the lampshade to glow. While it may seem like nothing more than a surreal light fixture, there is more at stake here as Laarman's lamp experiment is designed to investigate alternatives to electricity. Despite controversy over the source of the cells used, no hamsters were harmed in the creation of the *Halflife Lamp,* as the cells were first cultured back in 1957 and amazingly are still alive today. Despite this longevity of this lineage, however, the cells would die of shock in transit to the debut of the device in New York City, highlighting the constant maintenance required when working with many organic materials.[27]

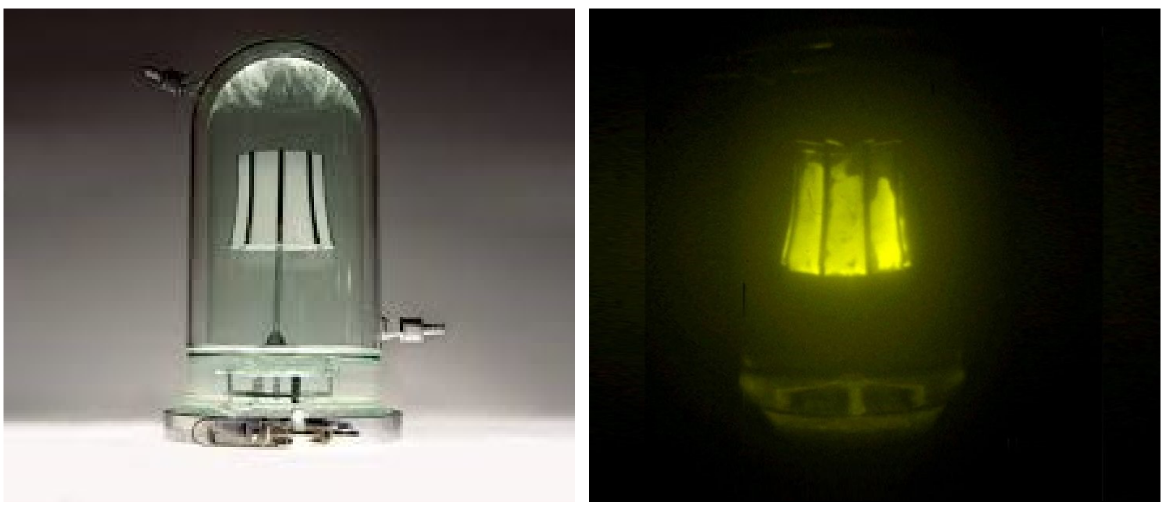


Fig. 10: ***Halflife Lamp (2010)***

[27] Myers, *Bio-design: Nature + Science + Creativity*, 141.

Fig. 11: ***Bio-light (2009)***

Jack Mama's and Clive van Heerdan's[28] *Bio-light* also makes use of the luciferase enzyme. *Bio-light* (Fig. 11) is an arrangement of glass chambers containing either bioluminescent bacteria or chemically charged liquid florescent proteins, the former of which is fed methane through silicone tubing that runs into each chamber.[29] During metabolism both the bacteria and proteins release luciferase and luciferin in their bodies which chemically reacts, producing light. In similar fashion to *Halflife Lamp*, this work acts as a way to create a light source that uses an alternative source of energy (methane is a plentiful by-product of waste that contributes to the greenhouse effect).

[28] Designer collaboration for Phillip's Design *Microbial Home* concept.
[29] Myers, *Bio-design: Nature + Science + Creativity,*, 97.

While a biomimetic approach offers aesthetically unique and sustainable approaches to creating works, it is not without drawbacks in some instances. MIT Media Lab's, Neri Oxman, for example, used 6500 silkworms to produce *Silk Pavilion.* The silkworms weave their cocoons onto a machine-made polyhedral silk frame that is suspended from a ceiling, filling in small gaps of the structure depending on where gravity, temperature, and lighting is most optimal for them (silkworms preferred the denser woven areas that had the most darkness).[30] The insects were removed before they completed their cocoon. This method for creating *Silk Pavilion* was met with concerns over the ethics of employing the insect to create the work. During the Biomimicry Summit in 2013, Oxman received negative feedback for *Silk Pavilion* from concerned audience members who felt she had exploited the silkworms' labour and disrupted its metamorphic life cycle.[31] Oxman attempted to clear up these issues explaining that she employs the *Bombyx mori*, a domesticated silkworm used by the silk industry that is already disallowed to go through metamorphosis. Oxman, however, doesn't elaborate on why using this species of silkworm is important since it could still be allowed to undergo metamorphosis and is arguably being depriving of its transformation for this work. Eduardo Kac's *GFP Bunny* is another example which raises ethical concerns over the treatment of animals for artistic endeavours. In *GFP Bunny,* Kac genetically engineers a rabbit to glow in the dark using a green fluorescent protein (GFP) derived from jellyfish. The point of the project, Kac tells us, is to publicize transgenic art, an art form he argues could contribute to the increase in

30 "Silk Pavilion," Mediated Matter, last modified 2018, accessed April 28, 2018, http://matter.media.mit.edu/environments/details/silk-pavillion.

31 31 Michael Fisch, "The Nature of Biomimicry: Toward a Novel Technological Culture," Science, Technology, & Human Values 42, no. 5 (January 2017): 795-821.

global diversity where artists can invent/reinvent lifeforms through genetic programming.[32] This signature Kac makes on nature leaves a human mark that sparks a debate over the ability for humans to change what already exists in nature without nature's consent.[33]

[32] Cary Wolfe, *What is Posthumanism?,* (University of Minnesota Pressm 2010), 160.

[33] Today genetic experimentation has only increased. CRISPR, for example, is a DNA sequence in bacteria that can be used to edit genes.

4.1 The Honeybee and Biomimesis

My MFA Thesis picks up on three particular honeybee traits: the honeycomb structure, the bee's vision (ommatidium optics), and the swarm's communication. I worked with these three aspects of honeybee physiology as they are ones which radically distinguish the honeybee from the human. The installation which has grown out of my research is called *Hive,* a name I have chosen for the relationship that exists between my body of work and the nesting habits of the honeybee. The beehive is an enclosed structure that houses the honeybee colony and their honeycombs. The space *Hive* is exhibited in acts like a beehive, where participants experience the honeybee's activity using the provided tangible clusters which model the three honeybee traits I am working with. Participants tessellate the clusters onto the magnetic wall and transform the space into a sensorial experience foregrounding the perceptual environment of a honeybee using three basic human senses (touch, sight, and hearing are used for this work). I've chosen these three humans senses for *Hive's* interactive platform as they correspond to the three honeybee traits I have chosen to explore. The sense of sight corresponds with the honeybee's vision, as I explore visually recreating how the honeybee sees for a human audience. Sound is fitted into honeybee swarming as I am recreating the collective volume of thousands of honeybees that one would experience if in close proximity to a swarm. Finally, touch is used in the shape and material used for *Hive's* hexagonal clusters, designed for participants to manipulate and access the other two sensorial components. Smell also was a consideration, as I wanted to incorporate the scent of beeswax but the prohibitive cost and material properties of beeswax meant I could not use it for *HIVE*. However, laser cutting the plywood singed the edges, producing a burnt wood odor which does contribute an olfactory component to the work.

4.2 Honeycomb: Geometric significance and contextual analysis

4.2.1 Honeycomb Geometry and Mathematic Fascination

The hexagon is an iconic form, one we most immediately associate with the honeybee and its intricate geometrical nest. The honeycomb which provides food storage, shelter, and a designated location for the Queen to lay her larva, is a lattice of hexagonal cells constructed through a metabolic process which entails worker bees chewing digested honey in order to convert it to a malleable sticky substance used to build up the comb. In the wild honeybees tend to build their nests in natural shelters such as the hollow of a tree or a rock crevasse. However, with the encroachment of humans upon their habitat they, like so many other creatures, have had to adapt to a human-built environment, seeking out small enclosures in structures and buildings in which to build their nests.

Humans and the honeybee having been working together for roughly 10,000 years resulting in honeybees becoming largely domesticated. Recognizing the nutritional and medicinal benefits of honey and beeswax, agrarian cultures have long ‘kept’ honeybees for various purposes. Monasteries, for example, began keeping honeybees in medieval times for a source of sugar and beeswax. This symbiotic relationship where we provide the bee with a preferential home to its liking in exchange for honey and wax is largely unchanged: one difference being the contemporary stackable wooden boxes or “Supers” used to house the honeybee colony as opposed to the naturally occurring enclosures undomesticated honeybee normally would inhabit. Wooden frames that contain a sheet of beeswax slot into these Supers with the wax acting as a substrate for worker bees to adhere their own secreted wax onto and create honeycombs.

Fig. 12: Cross section of a Mud Dauber wasp nest. Cells are filled with spider carcasses varying in size and encased in mud.

Over millennia the honeybee has worked to refine its hexagonal home, improving on that of its biological predecessors. Spheciforme wasps, a classification of wasp dating back to the Cretaceous period (145.5 to 66 million years ago) and still in existence today, are believed to be the honeybees' early ancestor. The spheciforme, like the honeybee, constructs a nest of cells to store larva and food. The spheciforme's nest however lacks the elegant geometry of the honeybee's hive. The omnivorous diet of the spheciforme meant that their prey varied greatly in size and therefore storage of these carcasses necessitated a more randomly structured system of cells (Fig. 12.). As the honeybee evolved to consume a strictly plant-based diet and produce a liquid nectar to (as opposed to the bodies of prey) to feed their young, they were able to standardize the size and shape of their food-storage cells.[34] A hexagonal packing method (demonstrated in Fig. 13.2) was the result of this progression to a plant-based diet, where the centers of the cells are aligned in a hexagon grid. This evolution of the honeycomb over millions of years predates what mathematicians have only in the last couple of Centuries been able to theorized and prove about hexagon packing.

At first glance the honeycomb might not seem an overly impressive structure. However, the immediately recognizable hexagonal shape which constitutes the honeycomb is in fact incredibly complex and stable. Along with squares and equilateral triangles, hexagons are a unique polygon that can tile, or tessellate, without any gaps or overlaps.[35] Of these three stackable shapes, the hexagon is the most efficient and stable per its area while occupying the smallest perimeter. In Fig. 13.1 and Fig. 13.2 we see a variation of stackable patterns using circles. In Fig. 13.1 the circles are arranged with their centers directly in line and in Fig. 13.2 the pattern is offset so the joined centers create a hexagon shape. The hexagonal pattern of the circles in Fig.13.2 diminishes negative space and results in a more stable and tightly packed structure. This highly efficient arrangement of spheres was postulated by astronomer Johannes Kepler in 1611 and became known as *Kepler Conjecture*. While Kepler's theory that hexagonal lattices provide the highest density arrangement was widely accepted for centuries, it was only proven in 1998 when mathematician Thomas Hales created an algorithm using computers that exhausted all the possible cases for packing geometrical shapes.[36] Hales harnessed a significant amount of computing power

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[34] David A. Grimaldi and Michael S. Engel, *Evolution of the Insects,* (Cambridge University Press, 2005), 454.
[35] Eli Maoor and Eugen Jost, *Beautiful Geometry*. (Princeton University Press 2014), 59.
[36] Ibid, 61.

to prove what honeybees had already achieved with hexagonal packing over millennia of evolutionary refinement.

Before modern mathematics, theorists tied explanations of phenomenon like hexagonal packing to the supernatural. Between the sixteenth and eighteenth centuries mathematicians like Isaac Newton, Nicolaus Copernicus, Luca Pacioli, and Galileo Galilei used their methodological observations as a platform to argue scientific proof of the existence of God, a notion that today is defined as *intelligent design*. Kepler too, supported this type of spiritual reasoning and linked his observations and theories of astrological and cosmological phenomenon to the Christian faith. For example, he explains Copernicus's heliocentric model of our solar system (planets orbiting the sun) through various religious allegories that point to a theological understanding of how planetary paths and velocity came into existence. While the sun's uniqueness could not empirically or philosophically be established at the time, Kepler argued the sun's central position defines planetary motion/orbit, a quality so unparalleled in our solar system for

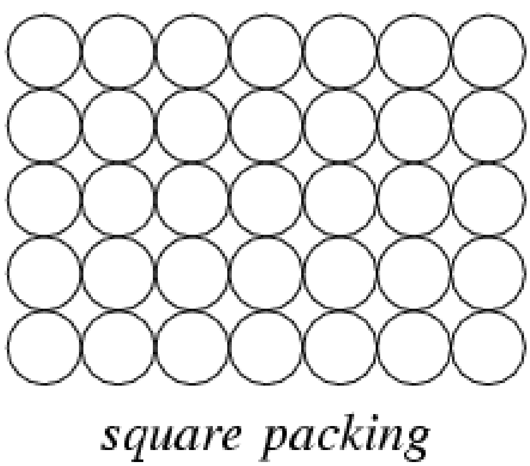

Fig. 13.1

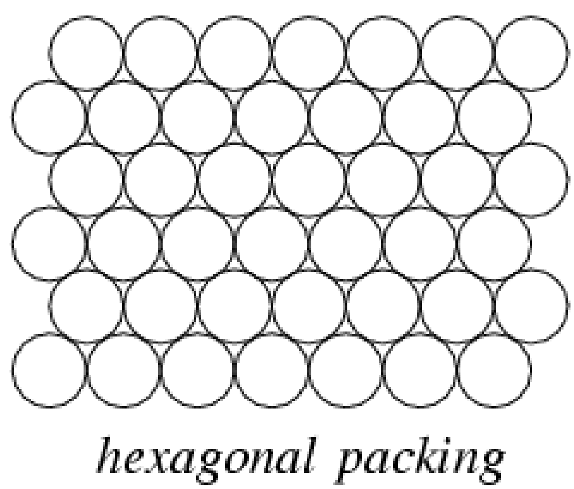

Fig. 13.2

his time that he could only point to its origins as being supernatural.[37] Kepler goes on to setup correspondence between planetary movements and platonic solids (shapes that can only be constructed with congruent, regular polygon faces and are limited to the tetrahedron, cube, octahedron, dodecahedron, and icosahedron) in his publication *Mysterium Cosmographicum* (1596). Here Kepler ventures to explain that by using these solids in tandem with Copernicus' heliocentric model of the solar system, we can understand planetary orbits around the sun by inscribing/circumscribing the solids into the orbits themselves. This coincidence of platonic solid fitting into planetary orbits is significant in that Kepler explains this unique phenomenon (the platonic solids' exclusive shape) points to a cognitive supernatural being. Amongst the numerous diagrams

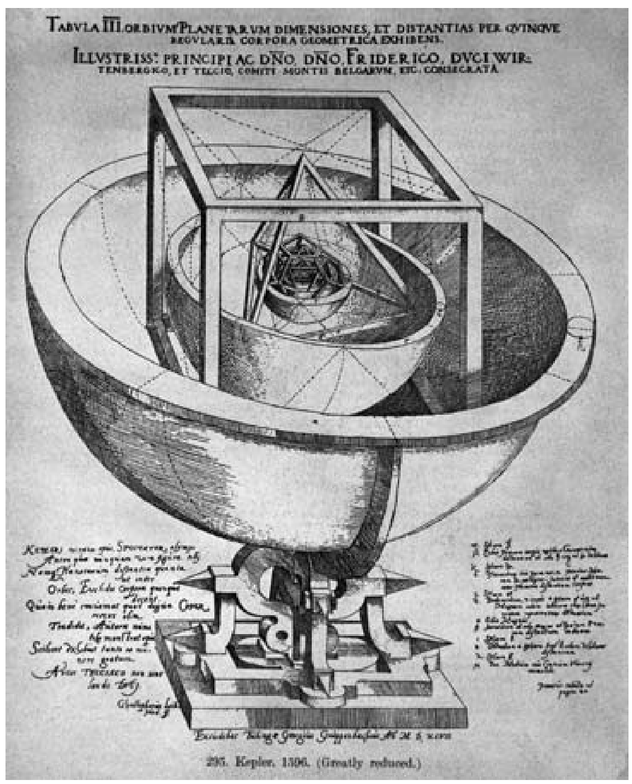

Fig. 14-Keplers Platonic solid model of the solar system

[37] Job Kozhamthadam, The Discovery of Kepler's Laws: The Interaction of Science, Philosophy, and Religion, (University of Notre Dame Press, 1994), 149-152.

illustrating his theories, he includes a model of the solar system based on Platonic solids (Fig. 14). While it is intended to scientifically articulate planetary machinations it also serves to give shape, quite literally, to the ephemeral nature of spirituality. The elaborate design of the object illustrated represents the solids used in a more spiritually divine way through the viewer's ability to see the solar system and geometric rules at play in a scale model, a point of view we are familiar with through the "bird's eye" perspective of maps and the prevalence of the omniscient narrator in literature or the all-seeing camera in cinema.

The fascination of geometric occurrences in nature is not limited to just Kepler's platonic model of the solar system. While Kepler ascribes the exquisite geometry of the heavens to a Christian god, throughout nature we find evidence of what we might think of as intelligent design, divine or otherwise implemented. For instance, hexagons appear in snowflakes, turtle shells, benzene rings, various animal scales, and rock formations such as the Giant's Causeway (Fig. 15) in Northern Ireland. Formed fifty to sixty million years ago the Giant's Causeway is the result of successive flows of lava inching toward the coast, and their subsequent repeated cooling from contact with water. Layers of basalt formed columns and the pressure between these columns sculpted them into polygonal shapes resembling hexagons.[38] While geologists now understand how this tessellated terrace came to be formed, prior to these scientific discoveries, these rock formations were the stuff of myth and legend. The name of this magical pattern of rocks—The Giant's Causeway—stems from Irish folklore which attributes its existence to a Giant

[38] *Britannica Academic*, s.v., "Giant's Causeway," accessed March 27, 2018, https://academic-eb-com.ezproxy.uleth.ca/levels/collegiate/article/Giants-Causeway/36732.

named Finn MacCumhaill who was attempting to build a causeway to the Scottish island of Staffa.[39] Like Kepler's divine explanation of understanding the universe, countless mythologies such as the origins of the Giant's Causeway provide us with a way of thinking about the world from a non-human perspective. While *Hive* is not tied to any particular myth, its visual appearance takes on large collective of clusters that is inspired by the Mormon religion. The hives I tend to with my hobby beekeeping are located in Mountain View, Alberta, a largely Mormon region of southern Alberta. While not Mormon myself, I experienced this religion growing up in the area and found its followers to be part of a highly collective society that metaphorically mimics much of the honeybees' social structure. Though this meaning is more a personal reflection, I feel it aids in giving *Hive* a cultural footing and something of a supernatural fascination that comes from myths, derived from collective tellings, that takes it beyond simply being a

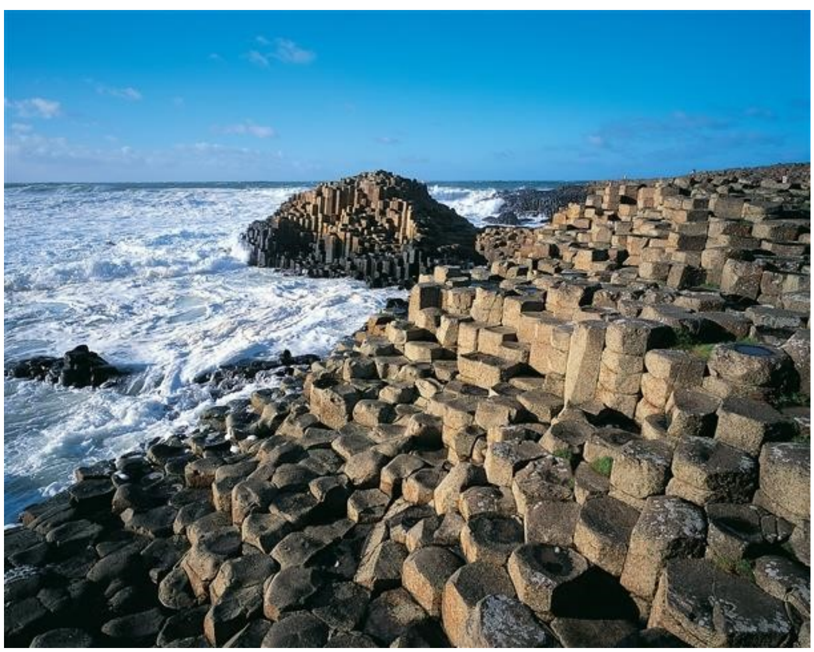

Fig. 15 – Giant's Causeway

[39] Ibid.

reflection of scientific findings. Myths give us a frame of reference that is supernormal; a plasticity of natural limits that lets the supernatural exceed human potential.[40]

The hexagon is a robust shape whose design value not only comes from millennia of refinement, but also from our human curiosity and fascination with the origins of such a complex, highly refined structure. I believe biomimesis isn't only exclusive to the mimicking of physical properties of an organic system but can also work the associations (spiritual, scientific, cultural) and meanings we have ascribed to nature and other creatures. The billboard for *Contagion* is a cultural example as the designers are playing off the anxiety society generally has directed towards bacteriums. Kepler's Platonic model of the solar system works with our spiritual associations, where astronomy (instead of biomimesis) is used to create an image that decentralizes the human perspective, granting us a divine view of the universe whose mathematical peculiarity is explained as being designed by a higher power. While firmly rooted in the secular, *Hive's* design, too, seeks to upset our usual reception of the world by letting us experience our surroundings through a simulation of the honeybee's perceptual apparatuses.

[40] Richard Grusin, *The Nonhuman Turn,* (University of Minnesota Press, 2015), 4.

Numerous artists such as Julia Lohmann, Eduardo Kac, and Joris Laarman have turned to the natural world as a source for their investigations. Many of these, including Penelope Stewart, Aganetha Dyck, and Tomàš Libertiny collaborate with honeybees to make works from beeswax. Libertiny's artistic practice, for example, uses the honeycomb in evocative ways. *Unbearable Lightness* (Fig. 16) is one such work in which Libertiny invites honeybees to construct their honeycomb on the surface of a clear plastic statue depicting the body of Christ. Over time the statue becomes immersed in beeswax with the

Fig. 16- Creation process of *Unbearable Lightness (2010)* on display in a glass crate.

resulting honeycomb taking on the plastic effigy's features. In doing this Libertiny is uniting and juxtaposing the qualities of the materials he is working with. The honeycomb, a soft and jagged substance created by natural processes, is contrasted with the hard and smooth surface of the plastic Christ.[41] The materials Libertiny adopts have a fragile quality to them however, resulting in the viewer's inability to touch his works.

In *The Seeds of Narcissus* (Fig. 17), Libertiny works with a large and fragile reflective glass bulb on to which the honeybees slowly adhere their honeycombs. The human-scale and reflectivity of the bulb references the Greek myth of Narcissus who, upon seeing for the first time his reflection in a pool of water, becomes so enamoured with his appearance that he stares at his reflection until dying of exhaustion. Libertiny duplicates and

Fig. 17.- Tomàš Libertiny's *The Seeds of Narcissus (2011)*

[41] Myers, *Bio-design: Nature + Science + Creativity,*, 206.

complicates this fate: the bees swarm to their reflection but as the attraction increases their mirrored twins are obliterated and the enchantment is broken. Along with this mythological context, Libertiny also explores the concept of *Ahimsa,* a tenet of Hinduism, Jainism, and Buddhism that means 'the avoidance of violence' and implores kindness towards all living things.[42] Using this tenet, Libertiny is expressing the vulnerability of biological and material existence wherein the delicate nature of the organic and manufactured materials he works with require handling in a non-violent manner to avoid damage.

4.2.2 Design Considerations

Whereas Libertiny's works use human-made materials in combination with a naturally made material, *Hive* focuses on one material—plywood—whose creation starts naturally and is finalized though human manufacturing, similar to pollen which a honeybee uses to "manufacture" beeswax through its own natural processes. The rigidity of plywood also allows participants to physically interact with *Hive's* clusters through touch.

Hive is comprised of numerous tangible and stackable hexagonal "clusters" which participants are invited to manipulate in order to construct an interactive honeycomb/wall. This wall assembly design is drawing off *WALL* (Fig. 18), a previous interactive work of mine which transforms the shape of an HIV cell into a building block for a prototypical wall design. Twelve interlocking cubes, each of which contain half of a protruding HIV-like cell can be combined in a limited number of ways to form a small wall whose

[42] Ibid.

prototypical façade makes use of a repeating organic form. *Hive*, too, makes use of this modular approach by using the hexagon as a motif for an interchangeable structure whose repeating shape reveals how capable natural patterns can be when used for human design.

Fig. 18- *Wall (2015)*

4.2 Honeybee Vision

4.2.1 Anatomy of the Ommatidium

Unlike our eye which has only one lens, the honeybee's eye is comprised of thousands of lenses called ommatidium. An individual ommatidia (Fig. 19) is comprised of a lens, a cone, nine photoreceptor cells (Retinular Cell), a Rhabdomere (rod like structure), and a screening pigment. The nine photoreceptor cells are sensitive to green, blue, ultraviolet, and polarized ultraviolet light, making the honeybee blind to red light. This arrangement of cells gives the ommatidium a mesh-like appearance when viewed through a microscope.

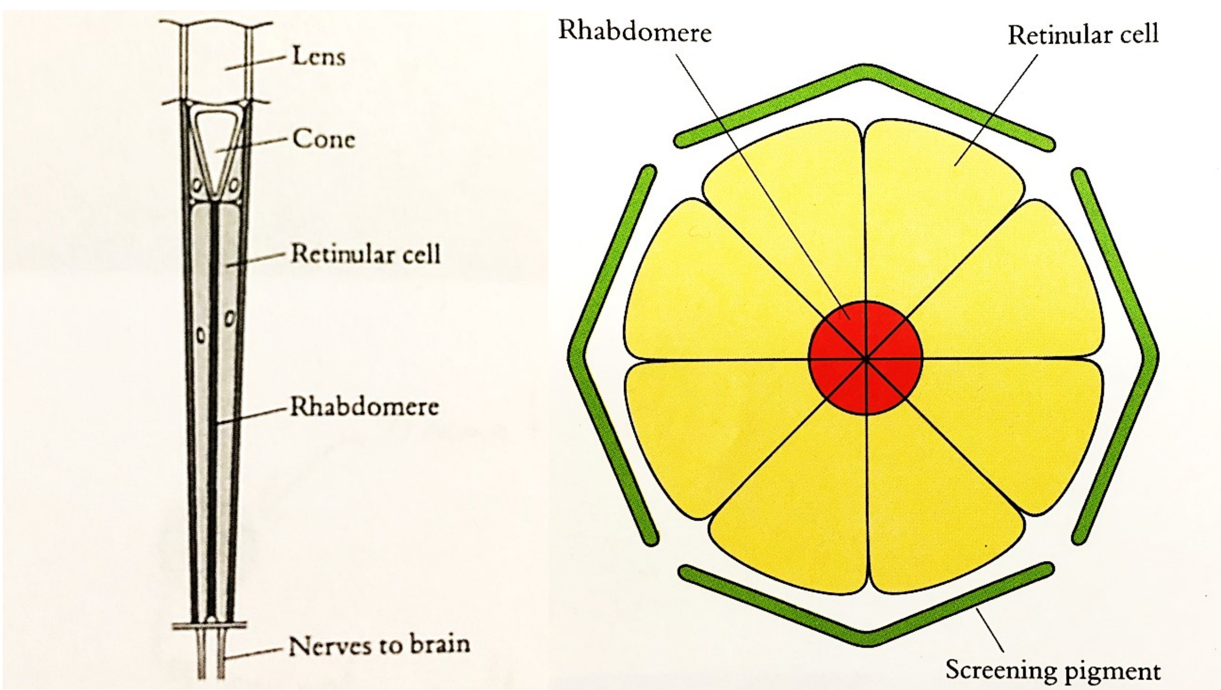

Fig. 19- Cross section of Ommatidia side and top.

Similar to how the rods and cones of the human eye work, the ommatidia sends colour information through an optic nerve to the brain which then forms an image. However, because of the number and size of ommatidia contained in a bee's eye, the light information received is fairly narrow, resulting in the image appearing grainy and needlepoint-like (Fig. 20). The density of ommatidium in the eye is dependent on the honeybee's gender. Worker bees (female) have around 4500 ommatidia in each eye, while drones (male) have around 7500. This results in the drone seeing in a higher resolution as they must be able, at a far distance, to readily spot the Queen for mating purposes. The Queen, however, has little use for vision as her tasks are limited to reproduction and keeping hive unity with pheromones, and therefore she only sees at a resolution of 3500 ommatidia per eye.

Fig. 20- Comparison of human vision (left) to honeybee vision (right).

4.2.2 Designing with the Ommatidium

In order to provide the participant with a device for experiencing the world from a non-human perspective, *Hive* uses light and colour to create a representation of what a honeybee sees. My inspiration for mimicking a honeybee's visual perception stems from an educational display at Fort Mason in San Francisco I was fortunate enough to experience several years ago: the general public are invited to don a set of large goggles comprised of an array of small lenses designed to simulate the ommatidium and let us see from a bee's perspective. The experience was disorienting; the sudden loss of clarity to one's vision makes it difficult to navigate our surroundings. *Hive* works with the idea of depicting the pixelated vision of the honeybee, as participants create their own patterns of light using the coloured LEDs housed inside the clusters. *Hive's* clusters imitate individual ommatidia, where each cell in a cluster emits a dot of light similar in shape to the broken down image in Figure 20 (right).

Fig. 21- *Pixelator (2007)*

One example I look to in producing a deconstructed image is Jason Eppink's *Pixelator* (Fig. 21) which physically deconstructs a video image into coloured blocks of light. The New York City Metropolitan Transit Authority (MTA) made eighty video screens available in 2003 at subway entrances in an effort to provide artists the opportunity to publicly showcase their video works. While the MTA was applauded for creating public spaces for exhibiting works, the scheme was also highly criticized as artists would have to pay $247,000 a month to have their works displayed on a single screen.[43] Financially, this is restrictive as most artists cannot afford this cost to display a work. This led to Eppink creating *Pixelator* (a foam board grid structure covered with a diffusion gel)[44] which he could freely place over top of the screens at subway stations. The foam grid captures coloured light emitted from the screen and then the diffusion gel averages the light into a single colour representative of that point in the existing image. The new image created by *Pixelator* appears as a grid of coloured light-filled squares representing a version of the existing image whose resolution has been greatly reduced through the diffusion of light. This degradation of resolution foregrounds the materiality of the existing digital image as the viewer becomes more aware of the pixels (small dots or squares of coloured light emitted in large quantity to build up an image) the video is composed of, a quality of image viewers aren't normally aware of due to the pixels microscopic size at a high resolution.

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[43] "New Ad City: Breaking down the cost of getting our attention". *New York,* last modified November 28, 2005, accessed May 3, 2018, http://nymag.com/nymetro/news/people/columns/intelligencer/15156/.
[44] "Pixelator," Jason Eppinks Catalogue of Creative Triumphs, accessed March 28, 2018, https://jasoneppink.com/pixelator/.

Hive uses the arrangement of coloured points in the same way as *Pixelator,* scaling up the ommatidium's process of deconstructing image into individual "pixels." Participants stack *Hive's* clusters into a grid of hexagons which visually imitates the layout of the ommatidium and the individual colours each ommatidia could collect, allowing us to perceive a honeybee's vision in a rudimentary way.

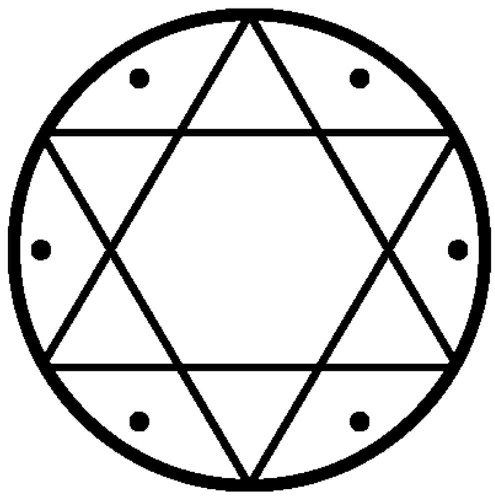

Fig. 22- Seal of Solomon

Each cluster of *Hive* is equipped with a lighting system that illuminates the internal structure of the cluster behind semi-transparent acrylic. Every 360 degrees of rotation results in the illumination cycling between two colours of the colour spectrum. I came to this method of interaction through the axial symbolism that exists within the hexagram shape Judaism uses symbolically in the *Seal of Solomon* (Fig. 22). In Judaism the six sides of a hexagram align with the six days of Genesis,[45] where the six colours of the rainbow describe each of the outer vertices of two interlaced triangles making the

[45] René Guénon, *Fundamental Symbols: The Universal Language of Sacred Science*, (Qunita Essentia, 1995), 219.

hexagram shape, and a centralized white light defining a day of rest.[46] This correlation of colour and geometry inspired me to use the hexagonal shape of *Hive* as a means for participants to interact with colour. While a simple button press can be sufficient in cycling through colour I wanted the interaction with *Hive* to be more meaningful by drawing the participant's attention to the physicality of the honeycomb through the handling of a cluster. Though the honeybee does not literally rotate its honeycombs or its ommatidium, *Hive* uses kinetic interaction to metaphorically connect participants to the honeybee's usage of shape and colour similar to the spiritual meanings associated with the two in the *Seal of Solomon*.

[46] Guénon, *Fundamental Symbols: The Universal Language of Sacred Science* 237-238

4.4 Swarm Intelligence

4.4.1 Swarms and Honeybee Democracy

Numerous species, for reasons of migration, foraging, and communication, have a tendency to gather in great, thick clusters. Known as swarming when referring to honeybee behavior, this phenomena affords the bees an effective means of collective communication and decision making.[47] A percentage (roughly 60% of worker bees) of the colony's population, including the outgoing Queen, will leave the hive due to overpopulation and produce a 'swarm,' which attempts to create a new hive elsewhere. The honeybees will bunch up onto a nearby surface, like a fencepost for example, near the parent hive (see Figure 23) and will remain there temporarily while scouting out a suitable new hive. Honeybees have chosen this method of huddling as a way for using

Fig. 23- Swarm inhabiting a fence post.

[47] Philip Ball, Nature's Patterns: A Tapestry in Three Parts (Flow), (Oxford University Press, 2009), 142.

their combined body mass to protect the Queen, whose pheromones keep the swarm aware of her presence. While the majority of the swarm remains at this temporary location, a group of individual scout bees will search for a new suitable location to setup a hive. These scouts seek enclosure: spaces that are at an optimal location to food sources, and contain enough space to inhabit. Upon returning, the scouts communicate their findings through a "Waggle dance" which is a series of back and forth motions performed at an angle relative to recently discovered location as shown in Figure 24, acting to inform the rest of swarm as to the quality of the potential hive it has investigated. This process takes between two to three days and essentially acts as a method for honeybees to vote on which scout has found the most suitable new nest. Honeybees in contact with a scout will judge the dance it performs and vote on whether or not it is more appealing than the displays of other scouts. If the observing honeybees are excited by the scouts waggle dance, they may leave to further investigate the potential nesting site and promote it through their own waggle dance upon returning to the swarm. However if a more exciting option arises from a different scouts waggle dance, the observing honeybees will literally headbutt and buzz at the less exciting scout until it stops its dancing, resulting in the elimination of less desirable nesting site from the poll.[48] Once a quorum of 80% of honeybees are in agreeance of the most suitable location, the entire swarm will relocate to the site. This phenomenon honeybees "voting" on their favourite location is known as honeybee democracy, a heuristic process that uses numerous simple actions (waggle

[48] Cornell University, "Tom Seeley: Honeybee Democracy," YouTube video, 57:05, February 15, 2012. https://www.youtube.com/watch?v=JnnjY823e-w.

dance) by individuals to solve a complex problem (swarm inhabiting the most optimal location).

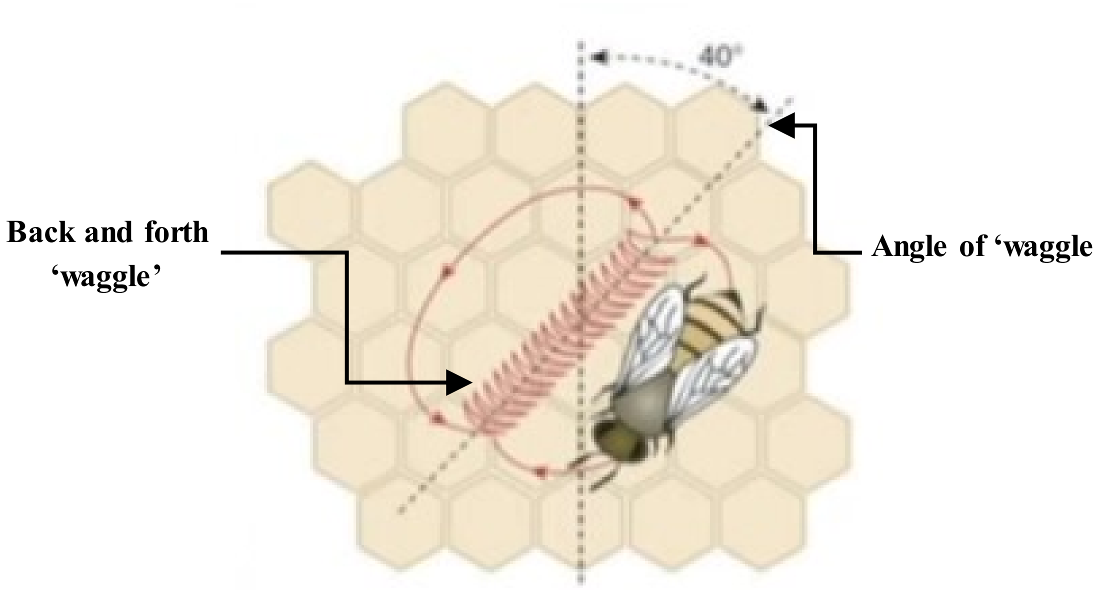

Fig. 24- Waggle dance

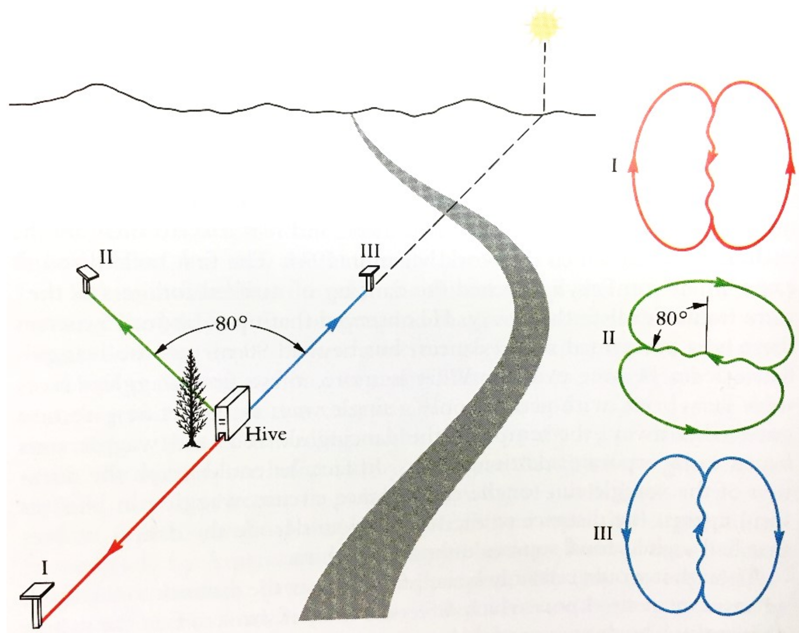

Fig. 25- Angle of the waggle dance orients the feeding station in relationship to the sun.

Research of swarming behaviour has been a testament to the longstanding relationship we have with these complex creatures. Greek philosopher Aristotle (b. 384 BC) was amongst the earliest observers of honeybees, noting cooperative behaviour exhibited by forager bees that lead other worker bees to flowers.[49] In 1823, Nicholas Unhoch documented the honeybees' dance, however, the purpose of the dance for recruiting foragers was not understood until experiments conducted by zoologist Karl van Frisch in the early twentieth century shed light on the phenomenon. Frisch set up stations that acted as food sources for foragers and located them at various distances and directions from the hive. Frisch observed the behaviours of the foragers waggle dance upon returning to the hive and concluded that this was a method for foragers to communicate the locations of food sources amongst one another (Fig.25).

Frisch's colleague Martin Lindauer took this observation of the waggle even further when noticing several honeybees in a swarm were coated in soot. Lindauer discovered these soot-covered honeybees were scouting a chimney as a possible nesting site and were returning to the swarm to perform a waggle dance that was specific in describing the directions to the chimney. Like the waggle dance in Fig.F, site direction is understood as the angle of the dance and the number of back and forth waggles indicates the distance to the site. Decades later, biologist Tom Seeley expanded on Lindauer's discovery adding that the number of times a waggle dance was performed indicated the quality of the site to other honeybees (Fig.26).[50]

[49] James L. Gould and Carol Grant Gould, *The Honey Bee,* (New York: Scientific American Library, 1988), 55.
[50] Cornell University, "Tom Seeley: Honeybee Democracy."

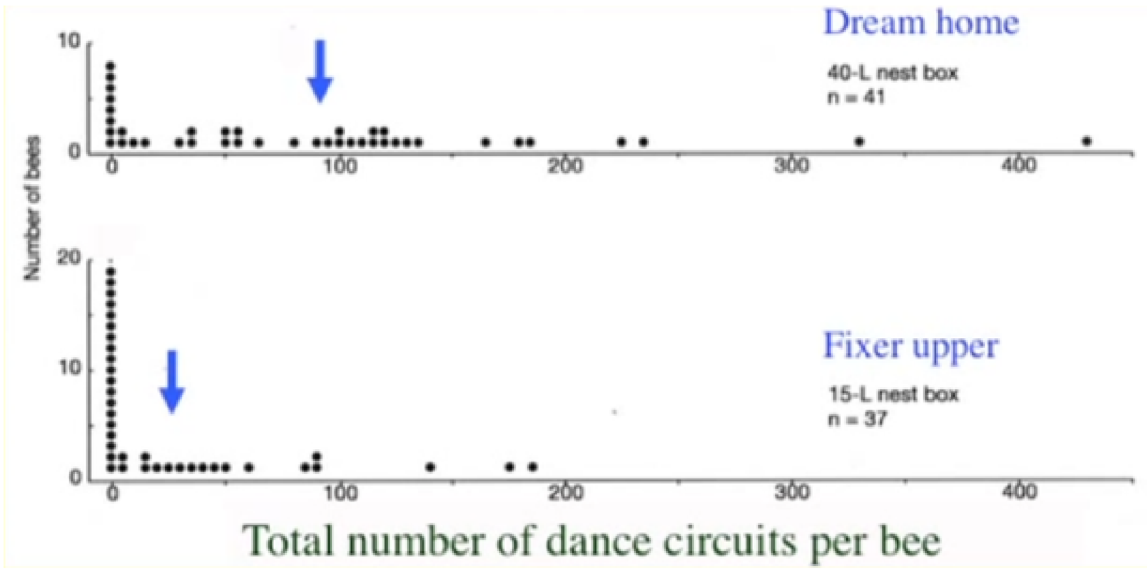

Fig. 26- Number of dances performed. The average is higher for the more suitable site.

4.4.2 Creating a Swarm

Participants experiencing *Hive* use basic interaction with clusters to construct a complex and collective soundscape, along with light and touch, designed to mimic the honeybee's physical means of communication. The shear density of the honeybees' swarm means that their excitement or displeasure with the scouts' performed information is, at least in part, communicated in a haptic manner. In a similar fashion, touch is integral to *Hive* as the external faces of each cluster are fitted with a conductive circuit that detects when the conductive circuit of another cluster comes into contact with it. The completed circuit then emit sound from a speaker inside the cluster. As participants gradually build their "honeycombs," a soundscape emerges representing a digital interpretation of a swarm's dense auditory accumulation. This is in accordance with *Hive's* purpose to provide participants with a form used to transform space through the application of biomimetic principles. The build up to immersion through participatory interaction seemingly brings *Hive* to life, an approach artist Philip Beesley implements throughout his works that seemingly come alive when in range of a participant. Proximity sensors attached to dangling acrylic fronds and whiskers become the antennae of Beesley's synthetic organisms, responding to participants' movements which animate these structures (Fig.27)[51]. Unlike traditional architecture that's intended to be structurally, Beesley's architecture behaves like an organism, constantly analysing and contorting its form to respond to changes its environment. Beesley terms this type of architecture "responsive architecture"—architecture capable of interacting and mimicking a primitive sentience—which he believes could one day lead to self-renewing structures.[52] Like Beesley's works, *Hive* requires participant interaction to unlock an organic-like response that mimics a sentient structure/organism. Participants become, in essence, scout bees soliciting a location (a steel wall) on which to build their honeycombs. As the clusters build up to create a structure *Hive's* sound quality changes producing a humming resembling that of a functioning beehive, signalling to participants the end goal of reaching a collectively chosen hive.

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[51] Ariane Lourie Harrison, Architectural Theories of the Environment: Posthuman Territory, (New York: Routledge, 2013), 18.
[52] "Liminal Responsive Architecture", Hylozoic Ground, Accessed, March 30, 2018, http://philipbeesleyarchitect.com/publications/hylozoic_ground/.

Fig. 27- ***Aurora*** **(2013) at West Edmonton Mall.**

5.1 Documentation

5.1.1 Constructing *Hive*

In order to arrive at a robust structure that allows me to securely house and yet retain access to the electronic components necessary to the interactive aspects of *Hive* I prototyped several iterations. *Hive*, as I've elsewhere outlined, explores the intersections of human and non-human design. As such, I chose to work with wood to construct my hexagonal clusters. However, for practical reasons which I detailed in the previous section, I employ manufactured plywood, so in fact, this “organic” material has actually been highly processed by the time I begun working with it, undergoing further manipulation on my behalf. After modelling the structure of a cluster in Rhino 3D I broke it down into individual 2D parts designed to interlock with one another. I used a laser cutter as an efficient means to cut out these parts. At one stage I considered making *Hive* completely from beeswax so I could conduct a material study that focused on directly using an organic material for biomimesis (similar to Jelte van Abbema’s experiments with bacteria in *Symbiosis* in Figure C). Participants would be more immersed in the honeybee’s perspective as they can touch and smell the materials a honeybee works with. Ultimately I decided against this due to the high price of beeswax and its brittleness when handled.

I made Prototype I (Fig. 28) from easily available MDF board and tested the structural integrity of a hexagonal prism design. In Adobe Illustrator I created the outlines for the various pieces to assemble into the hexagonal prism structure which I refer to as a “cell.” The cell's dimensions take into account the size of an Arduino Uno, as it is the largest electronic component used in the work. A tongue and groove design is used to connect the front and back pieces to the side pieces.

During the cut numerous issues became apparent due to the MDF containing large amounts of chemicals that are a binding agent. This makes it difficult for the laser to cleanly penetrate the board and as such, numerous passes (seven in total with the laser at its highest power setting) were require to cut the pieces out. This caused excessive singeing on the materials edges and soot rubbed off when the pieces are handled. Despite this, I glued the pieces together resulting in a very solid structure.

Fig. 28- Prototype I

Prototype II (Fig. 29) builds off Prototype I and uses the finished structural pattern. This version was designed using Rhino to help visualize the complexities of the design in three dimensions. The front face multiplies the single cell into a cluster of three joined cells. The new cluster shape resulted in some of the rectangular exterior edges overlapping, so I modified the pieces to vary slightly in width. I added interior pieces that slot into the front and back faces to retain rigidity. Prototype II is built from Nordic Pine plywood due to the previous issues I had laser cutting MDF. Pieces cut easily this time (two passes with the laser at full power), and no significant singeing occurred. I then assembled the pieces using hot glue as a temporary adhesive while the wood glue dried.

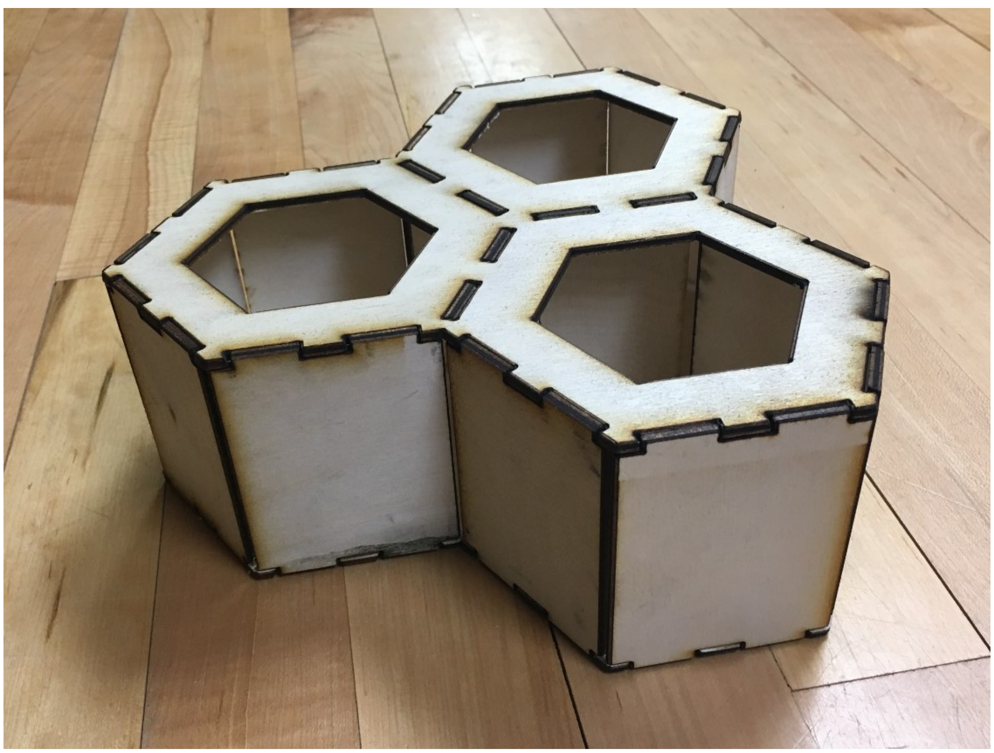

Fig. 29- Prototype II

Prototype III (Fig.30) was the final prototype I created and used the structural design of version II. In this version I added the electronic components for testing user interaction with a cluster. The hardware included:

- -Arduino Uno programmed with the first iteration of code.
- -MPU 6050 accelerometer to detect angle for cycling LED colours.
- -XBEE S1 wireless receiver/transmitter to send motion detection data to other clusters.
- -HY-SRF05 ultrasonic sensor to detect motion of participant near cluster.
- -3 RGB LEDs that activate when motion detected.
- -9V Battery.

I scraped both the XBEE and ultrasonic sensor after testing this version as the motion detection was not precise enough. As well the design was too small to properly fit an Arduino; the exposed electronics out the cluster's open faces made the appearance too busy.

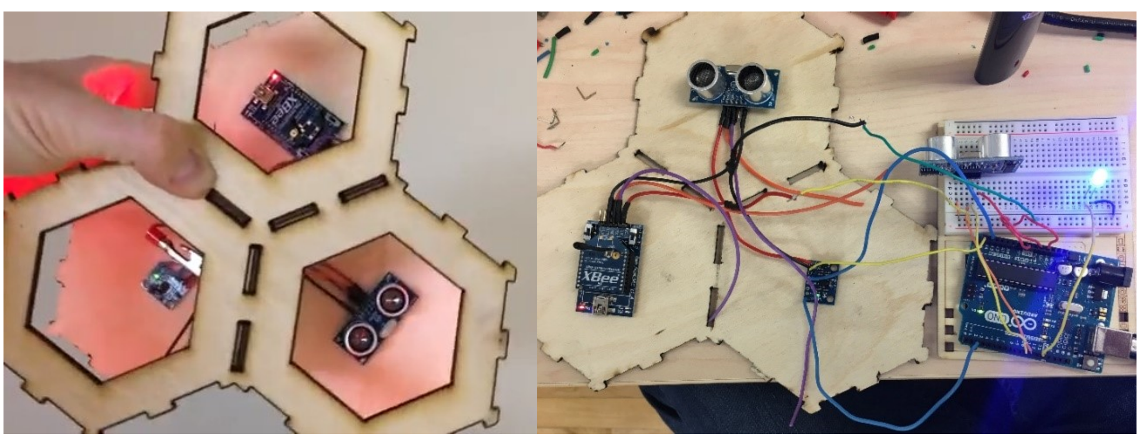

Fig. 30- Prototype III

The final version of the cluster scaled the structure up to allow the Arduino and new additional electronics to fit. An Adafruit battery shield is mounted on top of the Arduino along with a 9V lithium polymer battery to power the electronics. This device comes with its own on/off switch extending the battery's life. In lieu of the removal of the motion sensors and wireless communication, I added 8mm diameter metal washers that act as sensors on the sides of the cluster. When a sensor from another cluster comes in contact, a circuit is created which activates a sound sensor, creating the audio experience I have discussed in section 4.4. Frosted acrylic panels were added which hid the electronics, but still allowed access to the Arduino, and better diffused the LEDs colour.

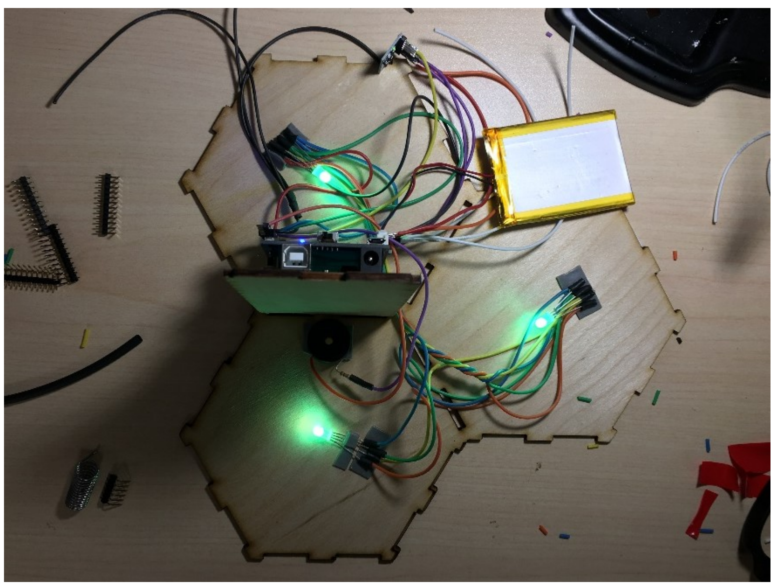

Fig. 31 – Electrical assembly of a cluster.

I then began an assembly line procedure for building mass numbers of clusters. I had an assistant that lasercut all the plywood pieces, while myself and other assistants completed the wiring soldering of the electronics. The inner supports and back piece glue together and the electronics mounted to the structure as shown in Figure 32. The programming is uploaded to the Arduino and the hardware is tested. Acrylic panels, and the front and sides are glued into place. Three, ¼" diameter magnets are super-glued on the back face.

The wall structure (Figure 33.) used for the clusters to magnetize too is made of wooden frames using 2"x2" sized boards and three steel sheets measuring 5'x6'-4". Each frame holds up one of the sheets and interlock so that the steel sheets seemingly appear flush with one another (total length of 15'). The steel and frame are adhered together using self-tapping steel screws and contact cement.

Fig. 32 – Wall assembly.

5.1.2 Public Reception

Hive was exhibited for four days in the evening at the James Foster Penny Gallery in downtown Lethbridge. In an attempt to bring curb appeal, the steel walls were positioned facing a window in the building that pointed out to the street. During the exhibit I was present as to observe how participants would interact with *Hive* and answer any questions pertaining to the work. In the future, however, I plan to better setup *Hive* in a way where I am not directly present and provide participants with instructions on how to use the work in advance. This is to allow individuals or groups a greater intimacy with the work as I found participants would sometime come to me questioning my own interactions with *Hive* and simply copy that formula. Ideally, once participants are familiar with the basic modes of interacting with *Hive* I want them discover their own ways of interacting with clusters.

The public's interaction with *Hive* were mixed in terms of how they engaged with it. I found small groups of people worked best as there seemed to be an exhibitionistic role a participant would take on in how they manipulated clusters. I would equate this to a performative element I had not initially intended for *Hive,* wherein a participant used clusters as a sort of paintbrush for expressing themselves using light and sound. Individuals in a group also could collaborate on creating a design of clusters that pulled away from *Hive's* intended interaction (largely the use of a magnetic wall). For example, one group of participants placed some clusters flat on the floor in front of the wall with several others trailing up the steel (Fig.34 middle-left). This gave the clusters a liquid-like effect that the group described as an homage to Salvador Dali's paintings of melting clocks. When a participant was not with a group, their interaction with the work dropped.

Collaboration was discernably less, for example, with small, introverted groups of people. I can infer that if participants are collaborating in a group and feel they have an audience, they are more likely to be engaged with *Hive* and for future exhibitions I intend to have the work in a more openly public space (outdoors or high traffic indoor area).

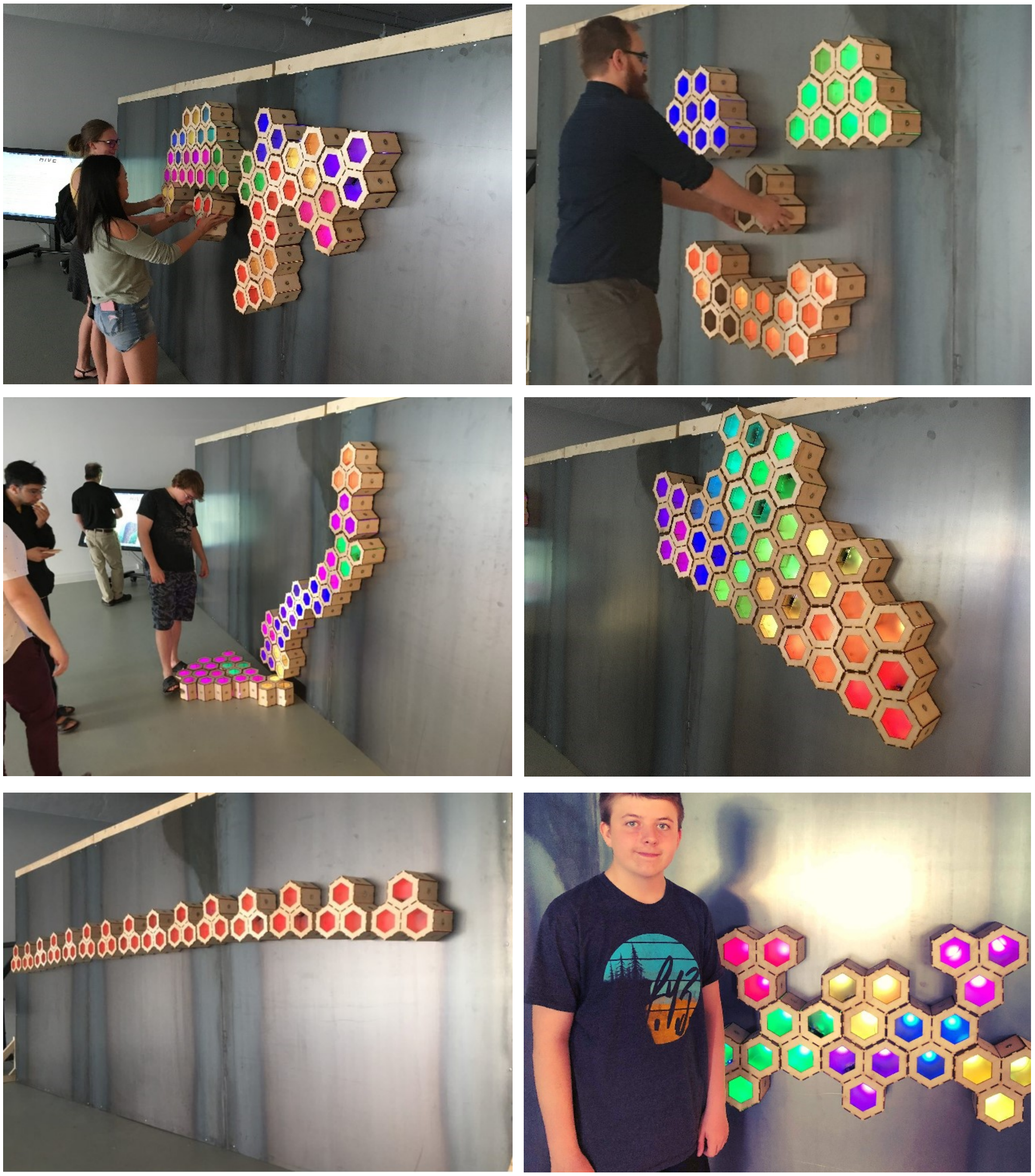

Fig. 34- Exhibition.

6.1 Conclusion

What I have covered in this paper explores the application of scientific and contextual analysis of the honeybee. I feel this research helped to shape the overall design and human interaction that occurred during the development and exhibition of this work. My biggest fear with *Hive* was that it would be taken as a gimmick due to its comparable usage to fridge magnet; this was not the case as people seemed to respond to the objects in ways that indicated an appreciation of them as something more than "toy" or mass-produced novelty.

Obviously, *Hive* doesn't succeed in being a sustainably built work due to many of the materials used in its creation coming from environmentally unfavourable manufacturing processes or sources. Rather, *Hive* is an exploration of and commentary on the possibilities for designing and making art afforded by biomimesis. By borrowing from nature we can render new forms that would be difficult to think up from a human-centered view of design. Libertiny's collaboration with the honeybee to envelope and texture human-manufactured objects with wax honeycombs, for example, would be not only difficult to manufacture with machines, but have little meaning if not for the understood patterns of hexagons we commonly attribute to the honeybee. As well, Marey's representations of insects are dependent on a direct, tangible mimetic correlation with his subject; the marks made by the wasp, for instance, grant us insight of the "other." With care and preservation of Earth's creatures we can continue to enjoy and carefully observe the diversity present in nature. A biomimetic approach to art making does just this: it constructs spaces and situations which prompt possibilities for a more receptive and respectful engagement with our world.

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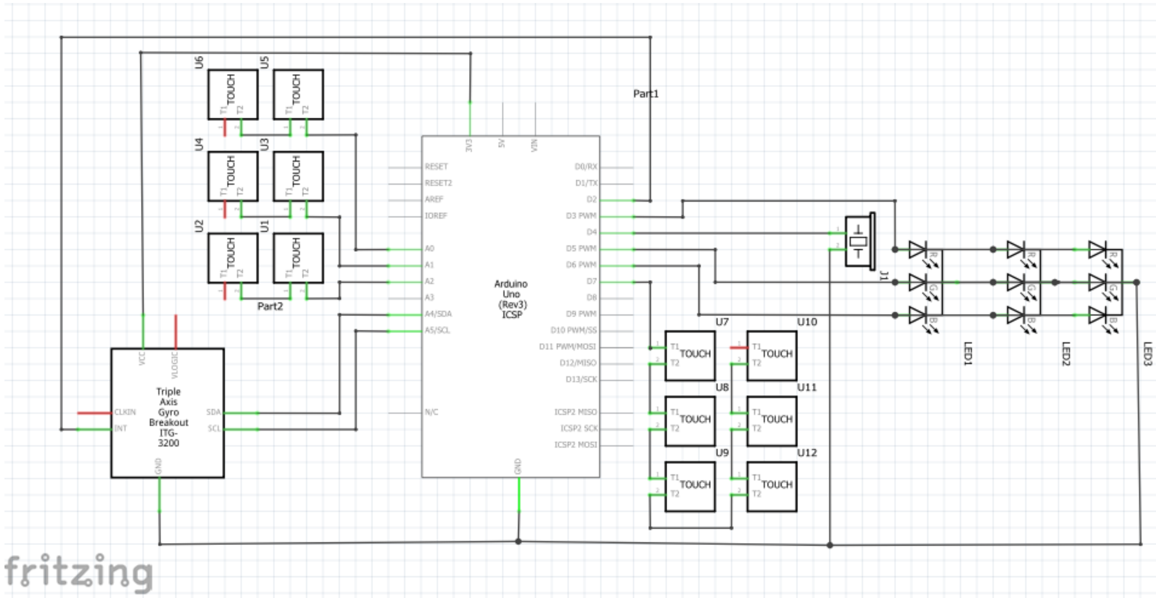
Appendix A: Wiring Diagram



Appendix B: Hive operating code/Arduino Uno

```
///////////////////////////
//HIVE operational code V2//
///////////////////////////
//      CREATED BY        //
//   Phillip Rockerbie    //
///////////////////////////

#include <Wire.h>
//MPU Data Access//
const int MPU_addr = 0x68; int16_t AcX, AcY, AcZ, Tmp, GyX, GyY, GyZ;
int minVal = 265; int maxVal = 402;
double x; double y; double z;
//RBG Values//
int red = 0;
int green = 0;
int blue = 0;
//RGB Pins//
int RPin = 3;
int GPin = 5;
int BPin = 6;
//Speaker Pin//
int piezoPin = 4;
//Checks for colour//
boolean rGate = true;
boolean oGate = false;
boolean yGate = false;
boolean gGate = false;
boolean bGate = false;
boolean pGate = false;
boolean mGate = false;
//Checks for colour fader//
boolean ROGate = false;
boolean OYGate = false;
boolean YGGate = false;
boolean GBGate = false;
boolean BPGate = false;
boolean PMGate = false;
boolean MRGate = false;

void setup() {
  Wire.begin();
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x6B);
  Wire.write(0);
  Wire.endTransmission(true);
  Serial.begin(9600);
  pinMode(7, OUTPUT); //PIN 7 transmits a pulse//
}

void loop() {
  Wire.beginTransmission(MPU_addr);
  Wire.write(0x3B);
  Wire.endTransmission(false);
  Wire.requestFrom(MPU_addr, 14, true);
  AcX = Wire.read() << 8;
  AcX |= Wire.read();
  AcY = Wire.read() << 8;
```

```
AcY |= Wire.read();
AcZ = Wire.read() << 8;
AcZ |= Wire.read();
int xAng = map(AcX, minVal, maxVal, -90, 90);
int yAng= map(AcY, minVal, maxVal, -90, 90);
int zAng = map(AcZ, minVal, maxVal, -90, 90);

x = RAD_TO_DEG * (atan2(-yAng, -zAng) + PI);
y = RAD_TO_DEG * (atan2(-xAng, -zAng) + PI);
z = RAD_TO_DEG * (atan2(-yAng, -xAng) + PI);

//Checks the Z angle which has been intergrated in the above sequence//
Serial.print("AngleZ= "); Serial.println(z);

//RED GATE 1//
if (z >= 0 && z < 90 && rGate == true)
{
  red = 255;
  green = 0;
  blue = 0;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = true;
  oGate = false;
  yGate = false;
  gGate = false;
  bGate = false;
  pGate = false;
  mGate = false;
  ROGate = false;
  OYGate = false;
  YGGate = false;
  GBGate = false;
  BPGate = false;
  PMGate = false;
  MRGate = true;
  // Serial.println("Red");
}
//RED GATE 2//
if (z >= 90 && z < 180 && rGate == true)
{
  red = 255;
  green = 0;
  blue = 0;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = true;
  oGate = false;
  yGate = false;
  gGate = false;
  bGate = false;
  pGate = false;
  mGate = false;
  ROGate = true;
  OYGate = false;
  YGGate = false;
  GBGate = false;
  BPGate = false;
```

```
    PMGate = false;
    MRGate = false;
    Serial.println("Red");
  }
  //RED<->ORANGE GATE 1//
  if (z >= 180 && z < 270 && ROGate == true && OYGate == false && YGGate == false && GBGate == false &&
BPGate == false && PMGate == false && MRGate == false)
  {
    red = 255;
    green = (z - 180) * 0.4; //range equation to reach orange
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = true;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = false;
    Serial.println("RO1");
  }
  //RED<->ORANGE GATE 2//

  if (z >= 270 && z < 360 && ROGate == true && OYGate == false && YGGate == false && GBGate == false &&
BPGate == false && PMGate == false && MRGate == false)
  {
    red = 255;
    green = (z - 180) * 0.4;
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = true;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = false;
    Serial.println("RO2");
  }
  //ORANGE GATE 1//
  if (z >= 0 && z < 90 && oGate == true)
  {
    red = 255;
    green = 72; //calculated green % to attain orange
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = true;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = false;
```

```
    ROGate = true;
    OYGate = false;
    YGGate = false;
    GBGate = false;
    BPGate = false;
    PMGate = false;
    MRGate = false;
    Serial.println("Orange");
  }
  //ORANGE GATE 2//
  if (z >= 90 && z < 180 && oGate == true)
  {
    red = 255;
    green = 72;
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = true;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = false;
    ROGate = false;
    OYGate = true;
    YGGate = false;
    GBGate = false;
    BPGate = false;
    PMGate = false;
    MRGate = false;
    Serial.println("Orange");
  }

  //ORANGE<->YELLOW GATE 1//
  if (z >= 180 && z < 270 && ROGate == false && OYGate == true && YGGate == false && GBGate == false &&
BPGate == false && PMGate == false && MRGate == false)
  {
    red = 255;
    green = 72 + (z - 180); //Equation to transition to yellow
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = true;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = false;
    Serial.println("OY1");
  }

  //ORANGE<->YELLOW GATE 2//
  if (z >= 270 && z < 360 && ROGate == false && OYGate == true && YGGate == false && GBGate == false &&
BPGate == false && PMGate == false && MRGate == false)
  {
    red = 255;
```

```
  green  = 72 + (z - 180);
  blue = 0;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = false;
  oGate = false;
  yGate = true;
  gGate = false;
  bGate = false;
  pGate = false;
  mGate = false;
  Serial.println("OY2");
}

//YELLOW GATE 1//
if (z >= 0 && z < 90 && yGate == true)
{
  red = 255;
  green  = 252;
  blue = 0;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = false;
  oGate = false;
  yGate = true;
  gGate = false;
  bGate = false;
  pGate = false;
  mGate = false;
  ROGate = false;
  OYGate = true;
  YGGate = false;
  GBGate = false;
  BPGate = false;
  PMGate = false;
  MRGate = false;
  Serial.println("Yellow");
}

if (z >= 90 && z < 180 && yGate == true) //YELLOW GATE 2
{
  red = 255;
  green  = 253;
  blue = 0;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = false;
  oGate = false;
  yGate = true;
  gGate = false;
  bGate = false;
  pGate = false;
  mGate = false;
  ROGate = false;
  OYGate = false;
  YGGate = true;
```

```
    GBGate = false;
    BPGate = false;
    PMGate = false;
    MRGate = false;
    Serial.println("Yellow");
  }
  //YELLOW<->GREEN GATE 1//
  if (z >= 180 && z < 270 && ROGate == false && OYGate == false && YGGate == true && GBGate == false &&
BPGate == false && PMGate == false && MRGate == false)
  {
    red = ((360 - z) * 1.42);
    green = 254;
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = true;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = false;
    Serial.println("YG1");
  }

  //YELLOW<->GREEN GATE 2//
  if (z >= 270 && z < 360 && ROGate == false && OYGate == false && YGGate == true && GBGate == false &&
BPGate == false && PMGate == false && MRGate == false)
  {
    red = ((360 - z) * 1.42);
    green = 255;
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = true;
    bGate = false;
    pGate = false;
    mGate = false;
    Serial.println("YG2");
  }

  //GREEN GATE 1//
  if (z >= 0 && z < 90 && gGate == true)
  {
    red = 0;
    green = 255;
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = true;
```

```
    bGate = false;
    pGate = false;
    mGate = false;
    ROGate = false;
    OYGate = false;
    YGGate = true;
    GBGate = false;
    BPGate = false;
    PMGate = false;
    MRGate = false;
    Serial.println("Green");
  }

  //GREEN GATE 2//
  if (z >= 90 && z < 180 && gGate == true)
  {
    red = 0;
    green = 255;
    blue = 0;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = true;
    bGate = false;
    pGate = false;
    mGate = false;
    ROGate = false;
    OYGate = false;
    YGGate = false;
    GBGate = true;
    BPGate = false;
    PMGate = false;
    MRGate = false;
    Serial.println("Green");
  }

  //GREEN<->BLUE GATE 1//
  if (z >= 180 && z < 270 && ROGate == false && OYGate == false && YGGate == false && GBGate == true &&
BPGate == false && PMGate == false && MRGate == false)
  {
    red = 0;
    green = ((360 - z) * 1.42);
    blue = (z - 180) * 1.42;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = true;
    bGate = false;
    pGate = false;
    mGate = false;
    Serial.println("GB1");
  }

  //GREEN<->BLUE GATE 2//
```

```
 if (z >= 270 && z < 360 && ROGate == false && OYGate == false && YGGate == false && GBGate == true &&
BPGate == false && PMGate == false && MRGate == false)
 {
  red = 0;
  green = ((360 - z) * 1.42);
  blue = (z - 180) * 1.42;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = false;
  oGate = false;
  yGate = false;
  gGate = false;
  bGate = true;
  pGate = false;
  mGate = false;
  Serial.println("GB2");
 }

 //BLUE GATE 1//
 if (z >= 0 && z < 90 && bGate == true)
 {
  red = 0;
  green = 0;
  blue = 255;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = false;
  oGate = false;
  yGate = false;
  gGate = false;
  bGate = true;
  pGate = false;
  mGate = false;
  ROGate = false;
  OYGate = false;
  YGGate = false;
  GBGate = true;
  BPGate = false;
  PMGate = false;
  MRGate = false;
  Serial.println("Blue");
 }

 //BLUE GATE 2//
 if (z >= 90 && z < 180 && bGate == true)
 {
  red = 0;
  green = 0;
  blue = 255;
  analogWrite(BPin, blue);
  analogWrite(GPin, green);
  analogWrite(RPin, red);

  rGate = false;
  oGate = false;
  yGate = false;
  gGate = false;
  bGate = true;
```

```
    pGate = false;
    mGate = false;
    ROGate = false;
    OYGate = false;
    YGGate = false;
    GBGate = false;
    BPGate = true;
    PMGate = false;
    MRGate = false;
    Serial.println("Blue");
  }

  //BLUE<->PURPLE GATE 1//
  if (z >= 180 && z < 270 && ROGate == false && OYGate == false && YGGate == false && GBGate == false &&
BPGate == true && PMGate == false && MRGate == false)
  {
    red = (z - 180) * 0.4;
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = true;
    pGate = false;
    mGate = false;
    Serial.println("BP1");
  }

  //BLUE<->PURPLE GATE 2//
  if (z >= 270 && z < 360 && ROGate == false && OYGate == false && YGGate == false && GBGate == false &&
BPGate == true && PMGate == false && MRGate == false)
  {
    red = (z - 180) * 0.4;
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = true;
    mGate = false;
    Serial.println("BP2");
  }

  //PURPLE GATE 1//
  if (z >= 0 && z < 90 && pGate == true)
  {
    red = 72;
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
```

```
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = true;
    mGate = false;
    ROGate = false;
    OYGate = false;
    YGGate = false;
    GBGate = false;
    BPGate = true;
    PMGate = false;
    MRGate = false;
    Serial.println("Purple");
  }

  //PURPLE GATE 2//
  if (z >= 90 && z < 180 && pGate == true)
  {
    red = 72;
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = true;
    mGate = false;
    ROGate = false;
    OYGate = false;
    YGGate = false;
    GBGate = false;
    BPGate = false;
    PMGate = true;
    MRGate = false;
    Serial.println("Purple");
  }

  //PURPLE<->MAGENTA GATE 1//
  if (z >= 180 && z < 270 && ROGate == false && OYGate == false && YGGate == false && GBGate == false &&
BPGate == false && PMGate == true && MRGate == false)
  {
    red = 72 + ((z - 180) * 1.01);
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
```

```
    pGate = true;
    mGate = false;
    Serial.println("PM 1");
  }

  //PURPLE<->MAGENTA GATE 2//
  if (z >= 270 && z < 360 && ROGate == false && OYGate == false && YGGate == false && GBGate == false &&
BPGate == false && PMGate == true && MRGate == false)
  {
    red = 72 + ((z - 180) * 1.01);
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = true;
    Serial.println("PM 2");
  }

  //MAGENTA GATE 1//
  if (z >= 0 && z < 90 && mGate == true)
  {
    red = 255;
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = true;
    ROGate = false;
    OYGate = false;
    YGGate = false;
    GBGate = false;
    BPGate = false;
    PMGate = true;
    MRGate = false;
    Serial.println("Magenta");
  }

  //MAGENTA GATE 2//
  if (z >= 90 && z < 180 && mGate == true)
  {
    red = 255;
    green = 0;
    blue = 255;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);
```

```
    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = true;
    ROGate = false;
    OYGate = false;
    YGGate = false;
    GBGate = false;
    BPGate = false;
    PMGate = false;
    MRGate = true;
    Serial.println("Magenta");
  }

  //MAGENTA<->RED GATE 1//
  if (z >= 180 && z < 270 && ROGate == false && OYGate == false && YGGate == false && GBGate == false &&
BPGate == false && PMGate == false && MRGate == true)
  {
    red = 255;
    green = 0;
    blue = ((360 - z) * 1.42);;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = false;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = true;
    Serial.println("MR1");
  }

  //MAGENTA<->RED GATE 2//
  if (z >= 270 && z < 360 && ROGate == false && OYGate == false && YGGate == false && GBGate == false &&
BPGate == false && PMGate == false && MRGate == true)
  {
    red = 255;
    green = 0;
    blue = ((360 - z) * 1.42);;
    analogWrite(BPin, blue);
    analogWrite(GPin, green);
    analogWrite(RPin, red);

    rGate = true;
    oGate = false;
    yGate = false;
    gGate = false;
    bGate = false;
    pGate = false;
    mGate = false;
    Serial.println("MR2");
  }

  delay(10);
```

```
  swarmTouch();
}

void swarmTouch()
{
  //This function detects if a pulse from PIN 7 registers on an Analog PIN//
  //If the circuit between 7 and one of three analog PINs is complete then//
  //speaker emits a random tone.                                          //
  analogWrite(7, 255);
  int currentA = analogRead(A0);
  int currentB = analogRead(A1);
  int currentC = analogRead(A2);
  Serial.println(currentA);
  //Single  Analog connection//
  if (currentA > 1010 && currentB < 1010 && currentC < 1010)
  {
    tone(piezoPin, random(100000), 5000);
  }

  if (currentB > 1010 && currentA < 1010 & currentC < 1010)
  {
    tone(piezoPin, random(100000), 1000);
  }

  if (currentC > 1010 && currentA < 1010 && currentB < 1010)
  {
    tone(piezoPin, random(100000), 1000);
  }

  //Double Analog connection//
  if (currentA > 1010 && currentB > 1010 && currentC < 1010)
  {
    tone(piezoPin, random(100000), 1000);
  }

  if (currentA > 1010 && currentC > 1010 && currentB < 1010)
  {
    tone(piezoPin, random(100000), 1000);
  }

  if (currentC > 1010 && currentB > 1010 && currentA < 1010)
  {
    tone(piezoPin, random(100000), 1000);
  }

  //Triple Analog connection//
  if (currentA > 1010 && currentC > 1010 && currentB > 1010)
  {
    tone(piezoPin, random(100000));
  }

  else
  {
    tone(piezoPin, 1, 1);
  }
}
```