Microcosm

An Autonomous Moss-based Air Purifier

A Thesis by Justin C. Trainor

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Microcosm is an autonomous moss-based air purifier that uses nature to overcome the functional and environmental issues of existing purifiers. Traditional HEPA-based air filters are stationary and expensive, requiring multiple units to clean just a few rooms. Our moss-based air purifier addresses these issues by giving the system the ability to physically move around your space, eliminating the need for multiple purifiers. Additionally, every component of the filtration system is 100% biodegradable while being just as effective as a HEPA-filter - all it requires is an occasional top-up on the water to keep the moss happy, healthy, and vibrant.

Abstract

Traditional HEPA air purification systems are effective at removing particulate matter but are limited in terms of purification area, environmental impact, and ability to remove volatile organic compounds (VOCs). Microcosm aims to address these problems through the creation of a mobile, autonomous moss-based air purification system. Moss is the ideal plant for this project due to its powerful air purifying ability, which is very effective at removing VOCs and large particulate matter. Additionally, its lack of traditional roots allows for a maximization of purification surface area. The air purification system itself is multilayered: air is first pulled through the moss, which filters out VOCs and particulate matter, before passing through a secondary activated carbon filter to remove any remaining VOCs. To allow Microcosm to navigate the home, the air purification system is built on top of a robust robotic platform that utilizes state-of-the-art robotic path planning software. Meanwhile, an integrated array of light, moisture, and nutrient sensors allow information from the moss itself to be fed into the pathing algorithm, resulting in autonomous maintenance of the moss layer. Outside of the robot base and electronic components, every aspect of Microcosm is fully recyclable or compostable, utilizing natural materials such as ceramics and wood.

Microcosm is more than just an air purifier; it's meant to provoke thought about climate change, the autonomy of non-human beings, and the impact of technology on our lives. Microcosm emphasizes the need for a symbiotic relationship between humans and nature; the presence of plant life in the home is scientifically proven to have both physical and mental health benefits, yet the life of the plant is often not considered. Through its movement, interactions, and functionality, Microcosm encourages users to appreciate the value that natural solutions can provide for us. Additionally, Microcosm has a variety of interactions built into it that make it more functional in a home or office setting. Users can set out air quality waypoints that Microcosm will monitor and move toward, should air quality deteriorate, while the onboard sensor array allows for real-time detection of pockets of unclean air.

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microcosm

“Travel and society polish one, but a rolling stone gathers no moss, and a little moss is a good thing on a man.”

John Burroughs, Conservationist

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Together, for a better world.

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Precedents & Prior Art

Introduction

House plants have become a nearly ubiquitous part of modern home decor since their initial introduction in the 1800s. Treasured for their aesthetics, plants are a proven way to bring nature into a space and provide a variety of benefits. The mental health benefits cannot be understated; our relationship with plant life is a fundamental part of the human experience. From a physical health perspective, plants can improve oxygenation of a space, regulate temperature by providing shade from the sun, and remove harmful organic compounds from the air. These benefits paint a clear path to today, where usage of plants is being pushed far beyond home decor into areas such as air purifiers, sensing devices, and even organic computers. To fully understand the present and future of this project, we must first understand the history of air purification, our relationship with plants in the home, and recent advances in plant technology.

Status Quo of Home Air Purification

We spend the vast majority of our lives indoors, with sleep alone constituting nearly a third of our total lifespan.[1] Air quality has a direct impact on health in a variety of ways, yet true air purification systems did not reach consumers until the 1960's with the introduction of home air filters.[2] Nearly 25% of Americans now own some type of portable air purifier, and in areas that are prone to natural disasters like forest fires, the number is much higher. Today, the consumer standard for air purification is set by the high efficiency particulate air filter, commonly known as HEPA filter. These filters pull air through a fiber mesh, typically made of plastic, to remove up to 99.97% of fine particulate matter (PM 2.5) via diffusion, interception, or impaction.[3,4] While these filters are very effective at removing particulate matter, they are unable to remove VOCs and are detrimental for the environment post-usage, as they are a dense source of microplastics in landfills. Consumer air purifiers today

An example of house plants in the 1800s[8] are also almost universally static, cleaning the air in a fixed space. There have been a few pioneers in building mobile air purifiers, such as the Ecovacs Airbot Z1, but these products have not gained consumer traction and rely on existing technologies such as HEPA filters.[6]

The History of House Plants

House plants first emerged as part of the creation of the middle class at the turn of the 19th century, rapidly becoming an essential part of the contemporary home. Plants were brought into a home for a variety of reasons, ranging from their innate natural beauty to the possibility of medicinal properties. Though there is some evidence that plants were initially considered primarily as living beings, they quickly evolved into elements of home decor, as evidenced by a change in language surrounding plants. Early writing around house plants focused on the care and wellbeing of the plant, by approximately 1850, much of the focus of writing shifted toward aesthetic value.[7] This trend has persisted to this day, despite a vast increase in our understanding of botany and the complex lives of plants. In modern times, house plants have become increasingly popular among Millennials and Gen Z.[9] As plant ownership booms, underlying questions about the role of plants in the home have resurfaced.

Advances in Plant Technology

As complex organic systems with a great variety of sensing and growing characteristics across species, plants communicate information in unique ways. The integration of manmade computing systems into plants, either integrated into the plant's existing anatomy or as an addition, has opened new possibilities for human-nature interaction. In Sareen et. al's 2019 paper "Cyborg Botany: Augmented Plants as Sensors, Displays, and Actuators", they coin the phrase Cyborg Botany as a description of the design process with which humans

The venus flytrap is a great example of a plant system that responds to stimuli[12] can build synthetic-natural hybrid organisms. The team built a variety of cyborg interactions into plants, such as touch sensors, motion sensors, and control systems defined by different leaves. Through these interactions and measurement of resulting stimuli, such as changes in touch, light, and sound, the system can be used for a variety of cyborgian applications.[10,11]

The possibilities that arise from Cyborg Botany are vast. From a practical standpoint, there are direct benefits for major industries, such as agriculture and healthcare. Crop systems with integrated bioelectronics can be programmed to track plant health and provide real-time modulation of key characteristics such as hormones; a 2017 study directly modulated hormone levels in Arabidopsis thaliana seedlings, providing additional control to their development.[13] Researchers at MIT have even managed to directly influence photosynthesis through the introduction of synthetic single-walled carbon nanotubes, allowing for higher rates of chemical transfer.[14] It's easy to imagine how these cyborgian systems could have major positive effects on reducing the impact of drought and other natural disasters wrought by climate change, especially with the integration of distributed AI systems.[15]

The autonomy of plants has become a topic of increased discussion in recent years, with a growing wealth of applied and speculative design research available on the topic. Harpreet Sareen, an Associate Professor of Interaction and Media Design at Parsons School of Design, has worked on several projects in the field of cyborg botany. One of Sareen's most popular projects, Elowan, is a great example of how cyborg botany allows plants to have more autonomy. To allow a plant to have agency over its movement, Elowan utilizes a series of tactically placed sensors to measure small changes in biopotential in the plant's leaves, stem, and roots. After amplifying these signals, a robotic wheelbase moves the plant based on the amplified input; for example, if an increase in photosyn-

Elowan[16]

thetic processes is detected in the leaf, the robot base will move the plant in a direction that amplifies these further.[16] At Purdue University, researchers have applied cyborg botany to crops, with an initial focus on soybeans. The resulting Soybots function similarly to Elowan, with a light sensor and robot base that allows the plants to navigate their surroundings and obtain optimal amounts of sunlight.[17] Generally, the robot bases for these systems are either built on top of existing solutions, such as the Roomba or Hexa robots, or on more hacked together solutions, such as remote controlled cars.[17-19] Interestingly, though there has been a large increase in research interest surrounding these robot-based plant cyborgs, there has not yet been a major commercial product that leverages the technology.

Of course, cyborg autonomy manifests in ways other than granting motion. Plantae Agrestis, a 2019 installation by Sareen and Kakehi, sought to explore how plants in a botanical garden environment might arrange themselves, rather than relying on arrangements from humans, breaking the notion of the "designed" space that often accompanies these gardens. The team noted that the plants distributed themselves throughout the space in a way that optimized their individual needs, and little "swarming" behavior was noted.[20] Sheikh et. al coins projects like these as "Plant(e)tecture", where the design of a given space or object takes into consideration the agency of the plants that are a part of it.[21] hortum machina B, designed by the Interactive Architecture Lab, is a large-scale geodesic sphere comprising 12 panels of various plants. Described as a "speculative cyber-gardener", hortum machina B uses signals from the plants to linearly actuate individual panels, moving the entire sphere. The underlying idea is to allow the plants to move to a space that works best for their growth, regardless of the existence of human-made structures.[22] These examples of cyborg botany are the key inspiration for the merging of robotics and plant life that make up this project.

CityTree, a large moss-based air purifier[25]

Cyborg Botany for Air Purification

Plant species have recently been investigated as possible tools for air purification. With the backdrop of the COVID-19 pandemic, the need for inexpensive and scalable air purification and filtration systems has become increasingly important, and plant life may present an interesting option. A researcher in South Korea tested the efficacy of moss as a fine dust filter, finding that it performed better than a HEPA filter.[23] Moss-based systems for air purification have exploded in popularity recently; a quick look at Kickstarter or Wired validates this trend, and there is clear consumer interest.[24-26] But mosses are not the only plants being considered for air purifiers: evidence shows that many house plants are effective at removing volatile organic compounds (VOCs), such as formaldehyde, from the air.[27] Some companies have pushed even further, with Lio recently unveiling a genetically engineering pothos plant allegedly capable of filtering air as efficiently as 30 house plants combined.[28] As more research and technology appears in the field, plants may begin to be seen as effective alternatives to mechanical air purification systems.

Motivation

A HEPA filter's final home[29]

The era of e-waste[30]

Motivation

This project comes at a time when new fears over existential threats to humanity seem to be mounting by the day; whether it's climate change, the destruction of entire ecosystems, or genocidal AI, you can pick your poison, and we are spoiled for choice. In the face of these looming disasters, Microcosm is designed in a way that directly addresses them. For example, the entire chassis/body of Microcosm is compostable or recyclable, bucking the trend of design to last forever and instead being designed for a fixed period. Designers today have an obsession with longevity, but the reality is that our speed of innovation leads to most things becoming trash within a year or two. Additionally, as we hand more and more of our lives over to computers, we must ask ourselves who is truly in the driver's seat. Is it still humanity? Will it be AI? Where does nature come in? Could it be… a synthesis of all three? Microcosm serves as a vessel for exploring how designers can respond to the changing landscape of our future.

Of course, outside of existential threats, Microcosm is a chance to address many of the issues that exist today within consumer products such as air purifiers. It's an amazing opportunity to see how adding mobility to a product can breathe new life into it; the variety of micro interactions that we can program into Microcosm is staggering. What if your air purifier could detect when you were cooking and drive itself next to the stovetop? Or if it learned your sleeping schedule and snuggled up with you each night at 10 sharp, providing you with a night of clean air? These interactions open the door for almost human-like relationships, and this effect is amplified when the presence of a living being, moss, is taken into consideration. By including a living plant as the main air purification device, Microcosm asks important questions about who should be prioritized in this exchange. For example, if we prioritize the health of the moss, Microcosm might linger in a nice area of indirect sunlight for a few hours rather than driving around and purifying other sections of the home. Are

A withering avocado plant[31]

human users willing to sacrifice some performance for the sake of the moss? Can Microcosm spur more conscious thinking about how human needs might conflict with the needs of the natural world? Questions like these are what drive my passion for this project, and I hope that viewers of this thesis and our exhibition ponder them as well.

Method & Approach

Moss adhering to the chassis

Housing for air quality monitors

Method & Approach

Overview

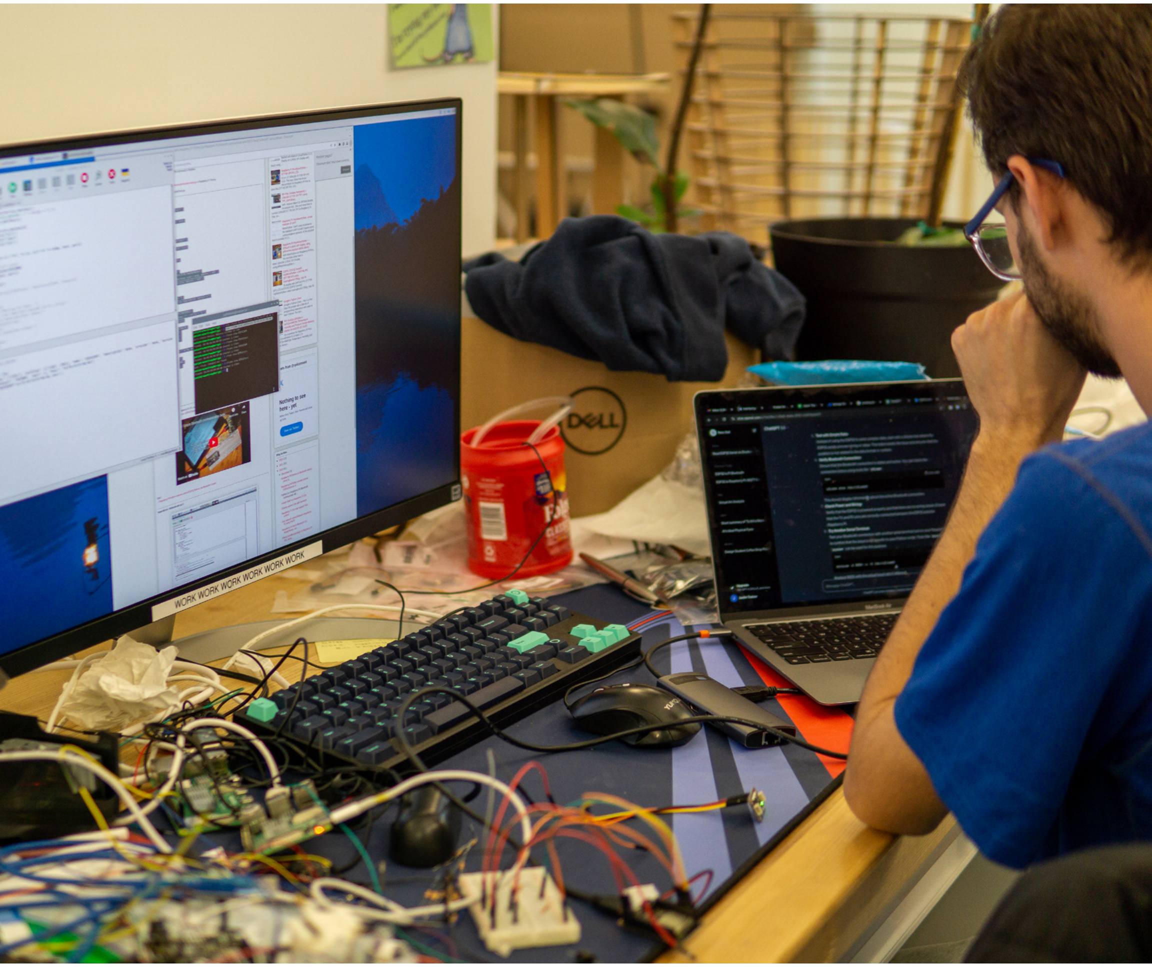
This project was completed in partnership with John Brechbill. John focused on the design of the system chassis and creation of the air purification system, while I focused on designing and coding the electronic and sensor systems and cultivating the moss. John and I collaborated on the fabrication of the chassis.

Designing the Autonomous System

To accomplish our goals of mobility and autonomy, we needed to build a system with a variety of different motors, sensors, and outputs. To expedite our process, we decided to build upon an established system, the iRobot Create3. This hackable platform is perfect for several reasons: it comes with a variety of integrated sensors, such as bump and IR distance sensors, utilizes a simple drive-on charging system, can support up to 20 pounds, and, perhaps most importantly, can be controlled over Bluetooth with Python. This allows it to perfectly integrate with the brains of the operation, a Raspberry Pi 4. The Pi, along with all other electronics, are powered by the Create3 and sit inside a waterproof housing.

In order for the system to know where the air needs purifying, we designed a small Bluetooth-enabled air quality sensor. This system uses an ESP32 as the Bluetooth and processing system and is connected to either PMS5003 air particulate sensor or a BME688 VOC and humidity sensor. Future iterations would integrate both types of sensor into one sensor array. To house these air quality sensors, we machined a wooden container out of the same wood as the top lip of Microcosm. This housing has a series of holes integrated into the top to allow air and contaminants to easily pass through.

Live data from the sensor is passed to the ESP32, which then sends the data to the Raspberry Pi via Bluetooth Low Energy. The code for synthesis of the data was written in Python and uses the iRobot Create3 SDK. The code is written in a way that



Coding amidst chaos

considers live data from each air quality sensor, as well as the onboard air quality sensor, to determine an optimal path for Microcosm. To achieve smarter pathing, the system uses a Simultaneous Localization and Mapping, or SLAM, algorithm developed by Steve Andrew Archer.[32] In addition to this system of purification sensors, Microcosm has an onboard BH1750 light sensor, which allow for tracking of the lighting conditions for the moss. Moss is susceptible to both too much and too little light, so modifications to the pathing algorithm can be made using these light sensors to ensure that the moss is not damaged. Finally, live data for local indoor air quality (IAQ) is handled by a BME688 sensor onboard. This data is then displayed to the user using a small LED indicator light on the top of the unit. To power everything, we utilized a 12 volt motorcycle battery, though this will be replaced for a more energy and space efficient battery in future iterations.

A final requirement to achieve autonomy is the watering system. This is handled by an array of ultrasonic misters, which resonate at a high frequency to atomize water. An onboard dehumidifier pulls water from air coming into the system and stores it in a reservoir. A small 3V water pump distributes water from the reservoir to each of the ultrasonic misters, which can be found on both the inside and outside of the system, allowing for misting of both sides of the moss. This whole system is controlled by an Arduino Uno, which modulates the flow of water from the pump. Users are informed of the water levels inside of Microcosm through another small LED indicator light on the top of the unit.

Cultivating and Testing Moss

To begin, we identified several species of moss that could work for our project. Sphagnum moss was a promising option, as research had shown its effectiveness in removing VOCs, but its long, stringy morphology made it too difficult to adhere to our chassis.[33] We then transitioned to sheet moss (Hypnum Imponens), which worked better due to its min-

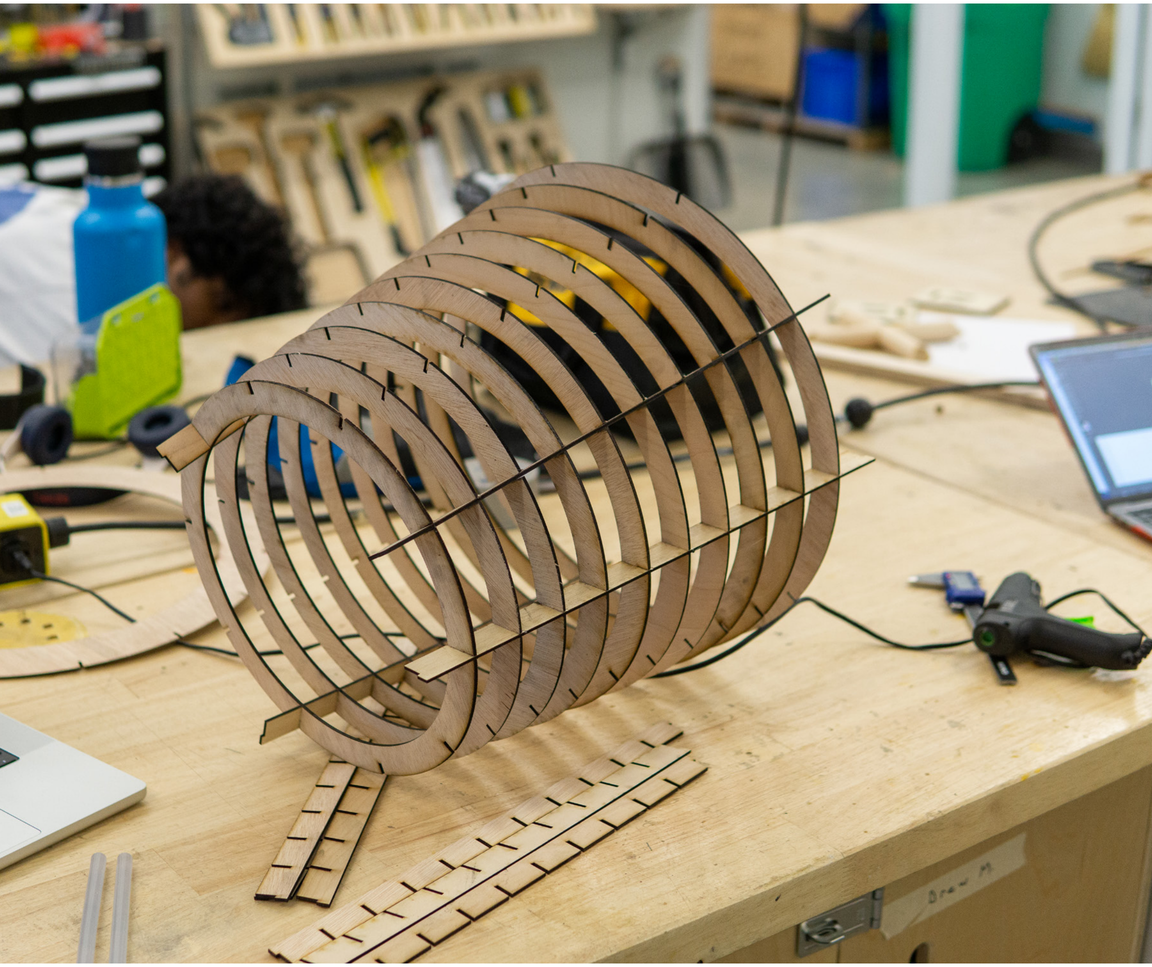
Testing the moss with smoke

imal height and large continuous surface area. Moss was stored in sealed plastic containers, misted with deionized water bi-weekly to maintain a humid environment, and exposed to 12 hours of indirect light per day. To adhere the moss to the chassis, a commercial product called Moss-Tac was used.

To test the performance of the moss when compared to a HEPA filter, we created a small experimental setup. The test media (either moss or a HEPA filter) was placed in a sealed acrylic box with a fan attached. First, we completed a control test with no filter, and, after a few seconds of the incense burning, an integrated air quality meter reached its maximum reading of 999 ug/m^3. Next, to test the removal of PM 2.5 (ultra-fine) particles, an incense stick was placed outside a fan that forced air through a HEPA filter, on the other side sat an air quality sensor. The HEPA filter was able to stabilize values around 30ug/m^3. We then tested the moss, which was able to achieve a stabilized level of 57ug/m^3. This test, while not 100% scientific, demonstrated to us that HEPA filters are still slightly better at filtering PM 2.5 particles, although the moss' ability to stabilize values at 57ug/m^3 means there was a significant number of particles being trapped. Finally, we completed a test focused on PM 10.0 (large) particles. The HEPA filter was able to stabilize the meter at 50ug/m^3, while the moss was able to stabilize around 30ug/m^3. This test was expected, as moss is particularly capable of trapping the larger particles. Overall, these results indicate that the moss system is effective at removing many types of particulate matter from the air. Future testing to measure VOC cleaning through the moss will help us reinforce this claim.

Fabricating the Chassis

While John handled the design of the chassis, we both worked on fabrication. We built more than 5 different models using cardboard or laser cut plywood, as shown to the left. Material choice was a key decision for us, as we wanted to use ful-



Gluing up the laser cut chassis

ly recyclable materials with little to no plastic involved. Wood was our initial choice here, but after some discussion, we attempted to make several versions using ceramics. We first built a large plaster mold for use with slip casting, but our calculations showed that the resulting pieces would be too heavy. We then moved to sheets of clay, which we wrapped around a foam mold. These clay wraps were allowed to dry and then were fired. Our first version was promising but warped quite severely, and our second version, while less warped, was incredibly fragile and shattered almost immediately after drying. Further investigation revealed that a ceramic chassis of this size would likely require over a month to dry properly before being fired. Therefore, we returned to wood, laser cutting the main body and using a CNC to fabricate the top cap.

Final Design

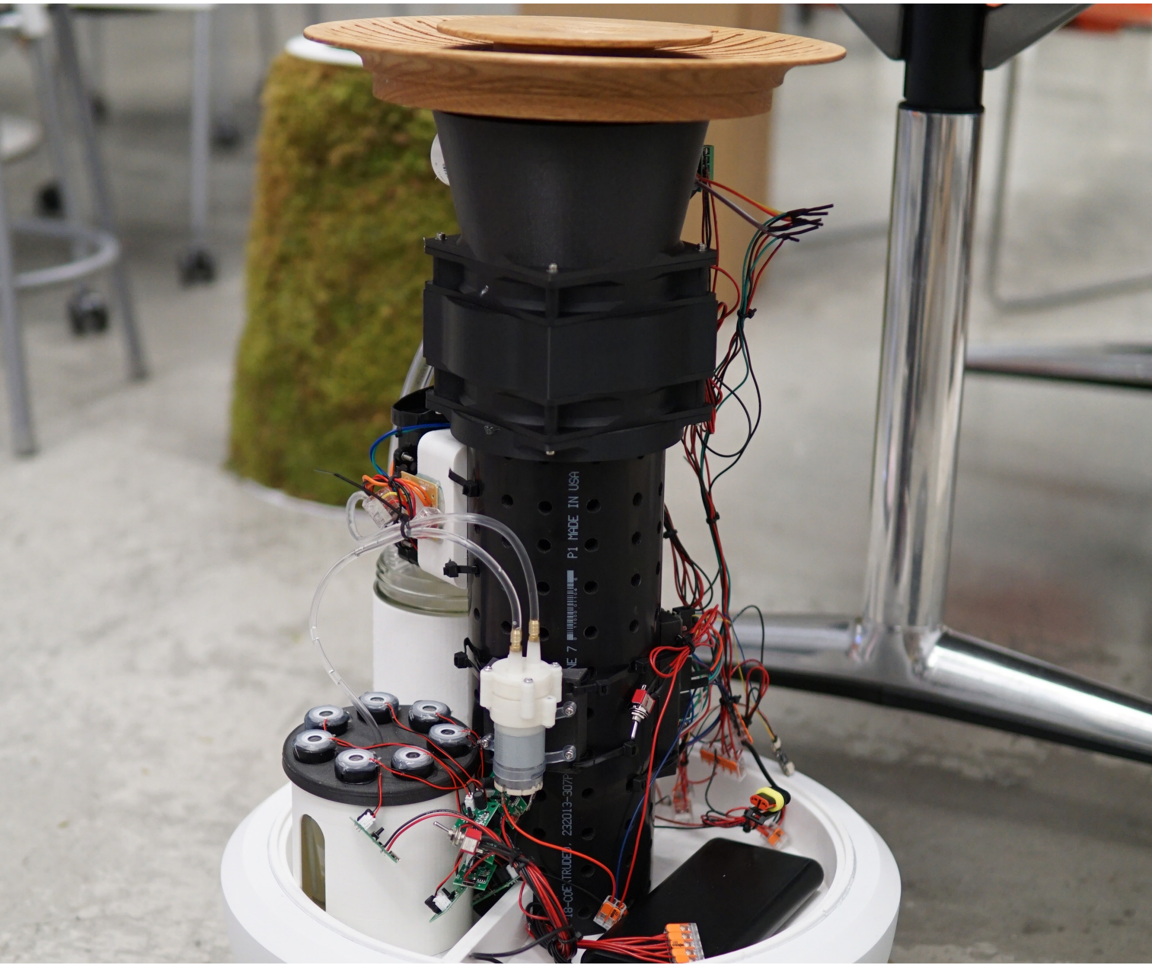
Microcosm in the home

Microcosm's final shape

Final Design

Our final design for Microcosm achieves our goal of creating an autonomous moss-based air purification system. The air purification system, shown to the left, utilizes sheet moss as the stage 1 filter for the system by pulling air through it via fan suction. As the air is pulled through the moss, VOCs and particulate matter are removed. After the air passes through the moss, it's forced through a secondary filter of woven coconut husk to remove any additional large particles. Finally, the air passes through a carbon filter to remove any remaining VOCs. Performance of this moss-based system was compared to that of typical HEPA filters in a controlled setup. Initial results of this test are promising, indicating that Microcosm's moss-based filtering mechanism was nearly as effective as HEPA filters for the removal of PM 10 and PM 2.5 particulate matter, all while actively removing VOCs from the air, which HEPA filters are unable to do.

The form of Microcosm is largely defined by the requirement of efficiently filtering the air while keeping the moss layer healthy. Initial designs ranged from vertical columns to large moss-filled caverns, but, in the end, we settled on a cone-shaped design reminiscent of a lunar landing capsule. We selected this design because it maximizes available surface area for the moss layer and allows for misting of water on both the inside and outside of the moss, all while creating a pleasing visual aesthetic. On the top of the form, we utilized Grasshopper, a generative design tool, to create the air channels, resulting in outlets that are both functional and visually distinct. As for materials, Microcosm's main chassis is intended to be fabricated out of a sintered porcelain. Porcelain was selected due to its high performance in moist conditions, as the small pore size when sintered mitigates the possibility of excess water retention. Additionally, porcelain can easily be recycled, a key design consideration for us. While ceramics are not often considered in robotics due to their fragile nature, we believe that the internal structure of Microcosm coupled with the outer layer of



Internal electronics system

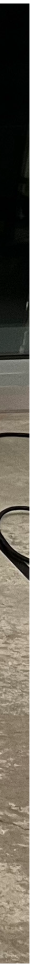
moss should provide ample protection. Due to time constraints, we were only able to fabricate a few mock chassis' using ceramics, but future work will go into refining this process. For the purposes of our exhibition, we fabricated a wooden chassis.

One of the major benefits of Microcosm's design is its ability to maintain the sheet moss layer autonomously. An integrated dehumidifier pulls water from the incoming air and stores it in a reservoir system, which can also be topped up by the user with the integrated water port shown to the left. The system is designed to be fully autonomous, but for homes in drier climates, these top-ups may be required on occasion. The water stored in the reservoir is pumped into a network of six ultrasonic atomizers, which deliver a fine mist of water onto the moss. Initial testing has shown that this system is capable of keeping the sheet moss happy and healthy indefinitely. Should the sheet moss grow and become unruly after a while, users can easily trim it back with scissors.

Of course, a key element of our final design is Microcosm's ability to autonomously move. Microcosm is equipped with an integrated light sensor, allowing for the onboard computer to identify which direction has the best lighting conditions for the health of the moss. Additionally, the system has a highly tuned VOC sensor, which allows for tracking and purifying of areas with high levels of these compounds. Rather than just measuring particle counts, the sensors we've selected utilize a variety of inputs from their surroundings, such as humidity, temperature, and gas make-up, to determine air quality. Several basic movement algorithms are included with Microcosm, such as returning to a docking station to recharge, conducting a randomized purification path of a room, or staying in place until VOCs in a given area reach acceptable levels.

The real magic of Microcosm arises with more advanced interactions. The primary interaction is an integration with a system of air quality monitors. In this system, the user places small air quality

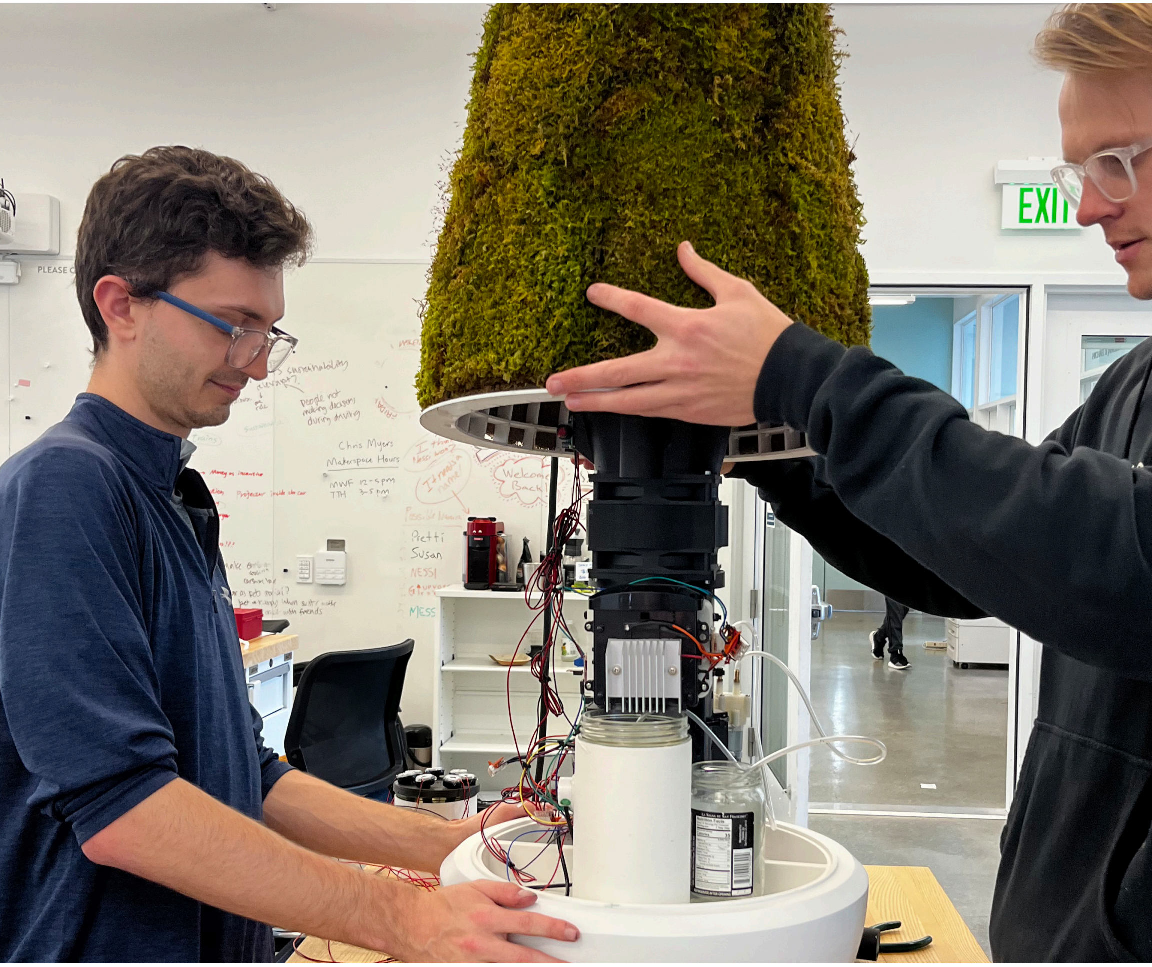
Moving near a user based on a custom routine



monitors, included as part of the Microcosm package, in various key areas of the home. Live data is sent from these monitors to Microcosm's onboard computer, which then intelligently builds its pathing algorithm to address areas with the worst air quality first. The main benefit here is that this all occurs in real-time. For example, if you blow out a candle in your living room, Microcosm is able to detect the increase in VOCs and particulate matter from the smoke and quickly drive over, reducing the amount of toxic fumes you breathe in. Furthermore, through the use of the Microcosm app, users can see the unit's real time location in their home, where it has traveled over the last 24 hours, and the live data from each of their air quality monitors. Finally, users have the freedom to build their own interactions through the app. Want Microcosm to greet you at your door each day at 5 PM? Done. Wish Microcosm would hang out next to your bed while you sleep, giving you the cleanest air possible? Easy. By providing users with these freedoms, Microcosm can be tailored to each individual user's needs.

Discussion

Microcosm basking in sunlight



Placing the moss purification layer

Discussion

Designing an Air Purifier

As we conducted our initial background research into this project and spoke with faculty and peers, we quickly identified a key question that users would ask: is this system really as good as existing air purifiers? We knew that answering this question in a satisfying manner would be one of the biggest challenges with this project. Though existing moss filters are available on the market, there isn't a ton of peer-reviewed research on them, so we had to make many discoveries ourselves. For example, we quickly learned that while moss is able to effectively filter out PM 10 (inhalable) particles, it is not as effective at filtering out PM 2.5 (fine) particles when compared to a HEPA filter. However, as previously mentioned, our testing leads us to believe that allowing Microcosm to clean an area for an extended period should make up for this. Additionally, we determined that air purification rates are directly related to moss surface area, so our design had to maximize the moss area as much as possible. While making these design decisions ensured that John and I knew that Microcosm was an effective filter, initial feedback from users indicated that our word wasn't enough; some sort of indicator was required. To satisfy this, we built an indoor air quality (IAQ) monitoring system into the chassis and wired it to a small LED indicator. This allows users to see the system removing VOCs from the air in real-time. Further testing after the integration of this system revealed that users were much more likely to believe that Microcosm could effectively clean the air.

A secondary aspect of designing this system was creating an autonomous planter. While we strove to create a truly autonomous system by integrating a dehumidifier and misting system, the system does require the user to top up the water, especially in dry environments. We wanted to use a low-power dehumidifier to reduce noise and power consumption, but this came at the cost of the amount of water that could be pulled from the air. Additionally, the

Live demo of Microcosm responding to air quality sensor moss system would likely require application of a liquid fertilizer every 6 months or so, which would have to be done by a user. As such, we've received quite a lot of questions about our claim of autonomy, and further work is required in this regard.

User Interactions with Microcosm

Once the overall idea behind Microcosm had crystallized, we found users asking many questions about what types of interactions they could expect to see. Some users expected it to function as a pseudo-pet, embracing a more whimsical feeling, while others expected a more sterile piece of technology. After some brainstorming and exploratory discussions with users, we settled on something in-between. We found that users preferred when Microcosm had some element of "personality", which we achieved through interactions such as the system detecting cooking fumes and moving toward the kitchen. This speaks to many people's innate desire to humanize their possessions, reflected in the fact that 80% of Roomba owners name their devices.[34] Additionally, some users remarked on the phenomena of house plant owners talking to their plants, and we explored the possibility of using voice commands. Despite this, we found that some users lost interest if we pushed the concept too far: for example, many users were unenthused by the concept of giving Microcosm emotions, either via sound effects or the integrated screen. Feedback on this sort of concept typically centered around cheapening the effectiveness of the device, which was a direct counter to our previously-discussed goal of building a sense of trust, so we scrapped any plans for this sort of interaction.

Future Work

Discussing next steps

An attempt at a clay chassis

Future Work

Looking retrospectively at Microcosm, it's clear that our work to this point represents the tip of the iceberg for the development of such a product. This is reflected in terms of material usage, form design, and breadth of interaction. In terms of material usage, while we made significant progress toward creating a ceramic chassis, time constraints prevented us from fabricating one that would be usable this semester. Initial discussions with more experienced ceramists indicate that a sheet of clay, like we were using, would take over a month to dry completely at our sizes. Alternative ceramics approaches like slip casting via a slap cast mold would likely be our next steps in terms of material exploration.

As far as form design, John and I iterated through many different forms, ranging from space capsule-esque designs to tubes with large internal moss-filled caverns. Optimization for air flow and water distribution would be a key aspect for us to consider in future iterations, as would more efficient pathways for air to leave the system. If these parameters could be further optimized, it would add more credibility to our claim that Microcosm is a truly autonomous system and could open the door for the usage of other plant species. To that end, a possible next step for Microcosm would be to move away from moss and to a new plant species such as a more traditional houseplant like a pothos or perhaps even a food/herb source like basil. While these plants (barring GMOs like Neoplants) don't have the same innate VOC removal properties, a soil-based air filtration system could solve this problem.

Finally, I think it's clear that the current Microcosm iteration barely scratches the surface in terms of possible interactions with humans. John and I have imagined dozens of such interactions; for one, Microcosm can easily be anthropomorphized, creating pet-like interactions such as greeting a user as they walk in the door or displaying emotions relating to air quality. Integrations with other IoT devices could allow Microcosm to better respond to stimuli in the home, such

The world's smartest side table?

as intelligently responding to changes in a user's routine. Finally, Microcosm could embrace secondary roles outside of air purification, such as serving as a moving side table. Any and all of these interactions would enrich and better inform the kind of product that Microcosm could be, and all are worth exploring in the future.

Conclusion

Clean air, cleaner design

Microcosm

Conclusion

Microcosm is more than a replacement for traditional air purifiers - it outperforms them in every regard. It's better for the environment, as it relies on nature to purify the air rather than large quantities of plastics like traditional HEPA filters; it's better for humans, as it can clean the air in multiple areas of the home while introducing a wonderful source of green life; and it's better for the plants involved, as they are taken care of autonomously without relying on human input. This device represents an important example of how designers can create environmentally friendly solutions without sacrificing performance in form or function.

As we look to the future and consider the threats of climate change, increasing isolation from one another and the world around us, and destructive technologies, I hope that Microcosm will inspire designers to take a different path. This project has so many interesting applications that we didn't have time to explore, especially within the realm of cyborg botany and mental health and wellbeing. The creation of autonomous systems that are less anthropocentric and instead consider the wants and needs of the contributing systems is key to addressing the challenges that we face. Microcosm shows us that handing the keys over to the natural world can begin to remedy the damage that humanity has done to it.

Bibliography

1. Indoor Air Quality. https://www.epa.gov/report-environment/indoor-air-quality
2. Perry Santanachote. Air Purifiers and the Cost of Clean Air. Published October 25, 2019. https://www.consumerreports.org/appliances/air-purifiers/air-purifiers-and-the-cost-of-clean-air-a6152505326/#:~:text=Now%2C%20an%20estimated%201%20in,be%20run%20around%20the%20clock.
3. US EPA O. What is a HEPA filter? Published February 19, 2019. Accessed November 19, 2023. https://www.epa.gov/indoor-air-quality-iaq/what-hepa-filter
4. What Is a HEPA Filter & How Does It Work? | ISO-Aire. ISO-Aire Air Purifiers. Accessed November 19, 2023. https://www.iso-aire.com/blog/what-is-a-hepa-filter-and-how-does-it-work
5. How to find an air purifier that won't keep you awake all night. NBC News. Published April 14, 2023. Accessed December 13, 2023. https://www.nbcnews.com/select/shopping/best-quiet-air-purifiers-ncna1260759
6. AIRBOT Z1. ECOVACS Website. Accessed November 19, 2023. https://www.ecovacs.com/global/airbot-air-purifier-robot/airbot-z1
7. Eibach J, Margareth Lanzinger, eds. The Routledge History of the Domestic Sphere in Europe: 16th to 19th Century. Routledge, Taylor & Francis Group; 2020.
8. How To Decorate a Victorian House with Plants. Old House Journal Magazine. Published June 21, 2011. Accessed December 13, 2023. https://www.oldhouseonline.com/interiors-and-decor/how-to-decorate-victorian-house-with-plants/
9. Must Reads: They don't own homes. They don't have kids. Why millennials are plant addicts - Los Angeles Times. Accessed September 27, 2023. https://www.latimes.com/home/la-hm-millennials-plant-parents-20180724-story.html
10. Project Overview ‹ Cyborg Botany: Augmented plants as sensors, displays, and actuators. MIT Media Lab. Accessed September 27, 2023. https://www.media.mit.edu/projects/cyborg-botany/overview/
11. Stavrinidou E, Gabrielsson R, Gomez E, et al. Electronic plants. Sci Adv. 2015;1(10):e1501136. doi:10.1126/sciadv.1501136
12. Photo by FUTURE KIIID on Pexels. Pexels. Accessed December 13, 2023. https://www.pexels.com/photo/venus-flytrap-3691258/
13. Poxson DJ, Karady M, Gabrielsson R, et al. Regulating plant physiology with organic electronics. Proc Natl Acad Sci. 2017;114(18):4597-

4602. doi:10.1073/pnas.1617758114
14. Giraldo JP, Landry MP, Faltermeier SM, et al. Plant nanobionics approach to augment photosynthesis and biochemical sensing. Nat Mater. 2014;13(4):400-408. doi:10.1038/nmat3890
15. Arya S, Pappa AM. Electronic plants: the future of agriculture and urban ecosystems? Trends Biotechnol. 2023;41(3):289-291. doi:10.1016/j.tibtech.2023.01.009
16. Overview ‹ Elowan: A plant-robot hybrid — MIT Media Lab. Accessed September 27, 2023. https://www.media.mit.edu/projects/elowan-a-plant-robot-hybrid/overview/
17. Purdue profs create Soybots, mobile micro-garden, to be on the go - Purdue University. Accessed September 27, 2023. https://www.purdue.edu/newsroom/releases/2015/Q1/purdue-profs-create-soybots,-mobile-micro-garden,-to-be-on-the-go.html
18. Light-seeking mobile houseplants raise big questions about the future of technology. doi:10.1073/pnas.1909980116
19. HEXA - Standard. Vincross. Accessed September 27, 2023. https://www.vincross.com/products/hexa
20. Sareen H, Kakehi Y. Plantae Agrestis: Distributed, Self-Organizing Cybernetic Plants in a Botanical Conservatory. Leonardo. 2023;56(1):41-42. doi:10.1162/leon_a_02315
21. Sheikh H, Gonsalves K, Foth M. Plant(e)tecture: Towards a Multispecies Media Architecture Framework for amplifying Plant Agencies. In: Media Architecture Biennale 20. MAB20. Association for Computing Machinery; 2021:87-99. doi:10.1145/3469410.3469419
22. designboom nina azzarello I. hortum machina B: a kinetic urban cyber-gardener that senses its surroundings. designboom | architecture & design magazine. Published April 22, 2016. Accessed September 27, 2023. https://www.designboom.com/design/hortum-machina-b-interactive-architecture-lab-04-22-2016/
23. Ahn D. Production of air purification verification system using moss. J Korea Acad-Ind Coop Soc. 2019;20(6):587-591. doi:10.5762/KAIS.2019.20.6.587
24. Flora: Innovation Air Purifier. Kickstarter. Published November 1, 2023. Accessed October 8, 2023. https://www.kickstarter.com/projects/airfilter-decore/flora-innovation-air-purifier
25. Michelle Mastro. The Briiv Air Filter Is the Moss-Powered Air Purifier You Need. Published June 9, 2023. https://www.architecturaldigest.com/story/briiv-air-filter-review

Bibliography

26. Moss-covered CityTree bench is designed to combat urban pollution. Dezeen. Published March 21, 2018. Accessed December 13, 2023. https://www.dezeen.com/2018/03/21/moss-covered-city-tree-bench-combats-urban-pollution-london-uk/
27. Kim HH, Yang JY, Lee JY, et al. House-plant placement for indoor air purification and health benefits on asthmatics. Environ Health Toxicol. 2014;29:e2014014. doi:10.5620/eht.e2014014
28. Neoplants - The Future of Plants. Published October 19, 2023. Accessed October 8, 2023. https://neoplants.co/
29. Photo by Tom Fisk on Pexels. Pexels. Accessed December 13, 2023. https://www.pexels.com/photo/bird-s-eye-view-of-landfill-3181031/
30. Martin Schlecht photos, images, assets. Adobe Stock. Accessed December 13, 2023. https://stock.adobe.com/contributor/201349656/martin-schlecht
31. _KUBE_ photos, images, assets. Adobe Stock. Accessed December 13, 2023. https://stock.adobe.com/contributor/207452780/kube
32. SteveAndrewArcher. roomba-mapping. Published online May 24, 2020. Accessed November 19, 2023. https://github.com/SteveAndrewArcher/roomba-mapping
33. Sirohi S, Kumar S, Yadav C, Banerjee D, Yadav P. Sphagnum: a promising indoor air purifier. J Environ Eng Sci. 2020;15(4):208-215. doi:10.1680/jenes.19.00051
34. Biever C. My Roomba's Name Is Roswell. Slate. Published online March 23, 2014. Accessed November 17, 2023. https://slate.com/technology/2014/03/roomba-vacuum-cleaners-have-names-irobot-ceo-on-peoples-ties-to-robots.html