BRDG Innovation Challenge

XyloBench: Sustainable Infrastructure for Water Reuse in Urban Green Spaces

Team 1: Greengineers

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THE GREENGINEERS TEAM

The Greengineers team comprises undergraduate students from various fields, including economics, computer science, and nearly all major engineering fields. There exist two co-leads, Adrian and Helen, who assist in overall project management through facilitating communication between group members and coaches, delegating tasks, and providing feedback on necessary items. Given the needs of our project, we've further divided the team into two key groups: hardware and software teams, led by Sandra and Adrian, respectively. While each group focuses on their respective tasks, they maintain open and continuous communication to ensure alignment and collaboration across the entire team.

Adrian Abraham

Computer Science, California State University, Long Beach

I lead weekly meetings, share updates, and delegate tasks to keep our project on track. In the next phase, I'll shift focus to backend development, handling system logic and component integration. Recently, I've become passionate about AI, especially its mathematical foundations, and aim to pursue a career as an AI/ML engineer or researcher in deep learning.

Arian Partovi

Computer Science, California State University, Northridge

For this competition, I will be focusing on the front-end development of an interactive dashboard. My primary goal is to design and implement a user-friendly interface that allows users to easily view data, monitor system performance, and make necessary adjustments. My career aspirations are to obtain my Ph.D in bioinformatics and lead a team of bioinformaticians, combining technical expertise with leadership to drive meaningful scientific discovery.

Jonathan Fuentes

Computer Engineering, California State University, Long Beach

In the first phase of this project, I supported research on the problem that our solution aims to address and also created visualizations for that data. In the second phase, I will focus primarily on integrating sensors on the microcontroller with low-level programming to ensure that the sensors function correctly. I am open to exploring different career pathways; however, my primary interests lie in embedded systems engineering and ASIC/FPGA design.

Nancy Vu

Economics and International Development Studies, University of California, Los Angeles

I am an aspiring accountant hoping to work for a public service agency or firm, and I am deeply fascinated by causes and means of addressing social inequality, whether that be from an environmental sustainability perspective or other lens. In the first project phase, I primarily worked on the budget allocation as well as background research on urban vegetation landscape and water scarcity to better understand our problem context and target audience. Next, I will join the software team to assist with the processing and display of data from our prototype.

Helen Yajaira Estrada

Aerospace Engineering, Santa Ana College

I serve as the team's co-leader and support the engineering sub-team. My role focuses on leading meetings, initiating conversations with our coaches, and project management. In Phase 2, I will continue within the engineering subteam to create a successful hands-on experience, making our idea come to life. My career aspirations are to work as an aerospace engineer where I will build spacecrafts, rovers, and telescopes that go beyond our current understanding of the universe. I see myself among the diverse scientists and engineers driving the discovery of new worlds.

Sandra Ramirez

Mechanical Engineering, San Jose State University

In Phase 1, I designed both the XyloBench prototype and long-term system, led the hardware sub-team, and developed the hardware plan. I researched groundwater recharge strategies and integrated those principles into the design. In the next phase, I'll lead the hardware team in building and integrating components. My long-term aspiration is to become an Automotive Design Engineer, working on high-performance vehicles in motorsports, particularly Formula 1. I'm passionate about automotive engineering, with the ultimate goal of launching my own brand of innovative electric cars that push the boundaries of performance, efficiency, and sustainability.

Steven Doan

Electrical Engineering, University of California, Irvine

In the first phase, I supported the documentation of hardware specifics and researched potential risks and mitigation techniques. In the next phase, I will aid in the construction of the bench and in integrating relevant hardware components. My future career aspiration is to work in the automotive industry to design hybrid and EV technology. This stems from my passion for consumer vehicles and drive to pursue more sustainable technologies. In addition, I'm open to exploring other forms of renewable energy and power, such as solar, to transition to a more carbon-free future.

INTRODUCTION: AN URBAN GREEN TOOL

XyloBench is a self-sustaining urban water reservoir that will support sustainable greenery while pumping water upward, all while providing a seating area for urban cities. The natural function of the xylem, a plant tissue responsible for transporting water from the roots to the leaves of a plant, and combining these concepts from biology with aspects of engineering design, inspired XyloBench's creation. With this project, we are addressing California's water conservation obstacles as well as the lack of greenery in urban landscapes. As urban areas grow denser and droughts become more intense and frequent, implementing smart, sustainable solutions, like our XyloBench, is vital to making sustainability accessible and visible.

The main structure for XyloBench consists of a bench that stores water in a reservoir, and similar to the xylem of a plant, the water stream will be pumped upwards to water vegetation and help maintain healthy plant life, even during dry periods. Our design allows us to integrate this solution into a city landscape to maintain functionality while also offering a smart solution to green sustainability. XyloBench combines practical feasibility with innovation to create a measurable environmental impact. We aimed to create a solution that not only addresses ecological concerns but also reconnects people to the systems that support life.

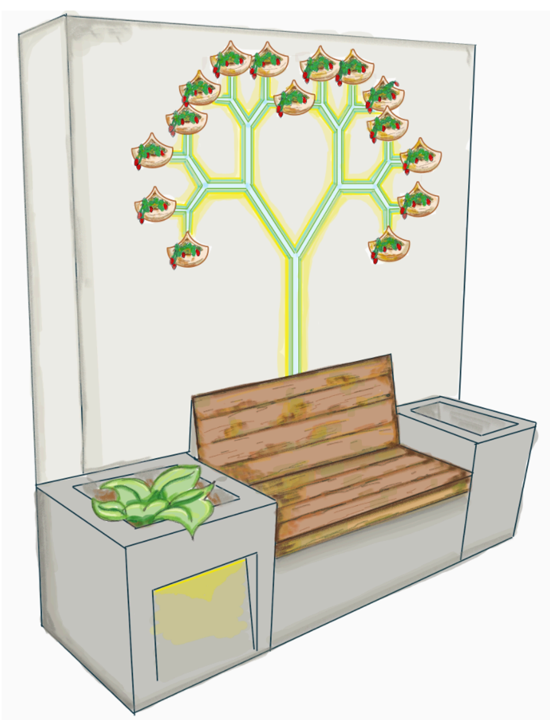


Figure 1: From afar, the design mimics an image, creating visual appeal both near and far. LED lights embedded in the water channels illuminate the "veins" at night. Each city can have custom-designed vines, with small plant pods, like herbs, growing along them. Water visibly flows through clear tubing, resembling sap in a plant. The bench also serves as the main reservoir, storing rainwater. This example shows a fractal tree, while the adjacent figure presents a variation with different vine styles, maintaining core functionality.

WHY THE NEED FOR XYLOBENCH?

The inspiration for XyloBench derived from our team's passion to add a touch of green to our beloved cities, where we so often see streets and neighborhoods deprived of this life source. Studies predict that increasing vegetation and tree canopy in Los Angeles neighborhoods to the county median coverage alone will collectively extend residents' life expectancy by over 570,000 years (Kivowitz, 2023). Greenery is essential to a community's overall health and well-being, not just in life expectancy, but also in mental health and stress management (Annotated Literature Review, 2024; Lee et al., 2015), so our project aims to do our part in reimagining the way that urban community spaces may look.

Our team recognizes that greenery distribution and income levels are negatively correlated (Wen et al., 2013), so many urban poor residents may not be able to afford both the space and money to invest in a front lawn or many flowers and plants. Furthermore, a study of green gentrification reveals that despite hopes for elected officials and local governments to take action, "perceptions of neglect and injustice" over generations have left some residents skeptical of public investment in their green spaces (Yudelevitch, 2019, p. 29). Therefore, XyloBench is intended for private, shared urban community spaces like the commons area in apartment courtyards, plazas, and museums. Private ownership addresses the skepticism associated with public projects, and it allows for ease of management and maintenance by the staff who oversee the shared space. At the same time, the shared nature of these urban spaces means that a larger community will be served compared to single-family homes or other low population density infrastructures.

WATER RECYCLING AND CONSERVATION

While long-term, sustainable urban green integration is our primary goal, water scarcity is also a major point of focus in our design in order to reduce the pressure on our already limited resources. Recent years have seen notable warm and dry conditions in California, including the hottest drought in the state's recorded history. The root cause of water scarcity and droughts stems from broader climate change, which can not be stopped or reversed within a short time frame, so conserving our limited water supply acts as a preparatory step in response to the more extreme climate changes to come.

Many cities already have existing infrastructure to prepare for droughts, but the high population density in cities means that there is also a higher demand for water there. As depicted in Fig. 3,

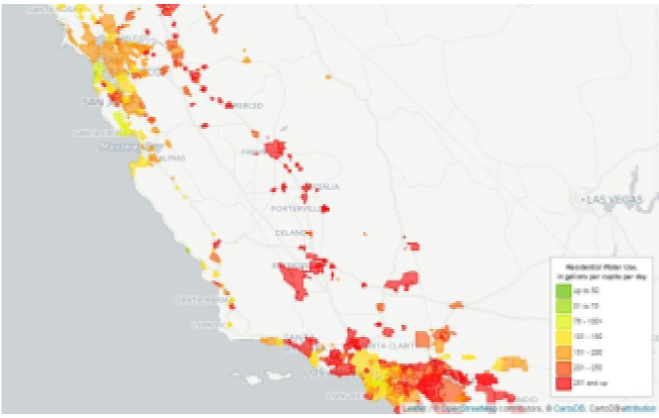


Figure 2: California daily residential per capita water use (Heberger, n.d.)

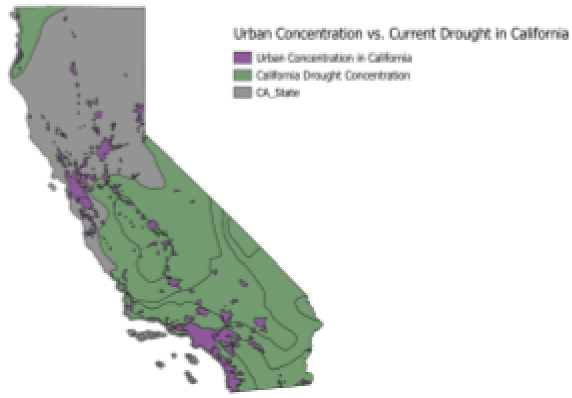


Figure 3: Urban concentration and drought in California 2012-2016 (Mount et al., 2021)

there is significant overlap between high residential water use, drought, and urban concentration in southern California, so once developed and in use, Xylobench will bring immediate benefits to our local communities by recycling rainwater for sustainability, resourcefulness, and personal growth through gardening. Since millions of Californians reside in cities, targeting urban communities first will allow us to reach a larger population audience and facilitate faster spread of our innovation; after all, innovations and cultural shifts often begin at the core of cities before spreading to other areas.

INNOVATION OVERVIEW

Due to the high population density typical of urban spaces, any addition of vegetation requires efficient space planning to ensure that the greatest number of people are served using the least amount of space possible. A model of vertical farming does just that by planting up rather than horizontally. We designed XyloBench using biomimicry, modeling its water flow system after the xylem in plants. Just as these plants use “veins” to transport water and nutrients upward against gravity, our design mimics this by using a network of tubes arranged in a fractal tree structure. These are natural structures that reflect the patterns found in nature. We also drew some inspiration from the Sponge City concept, which is an urban planning concept that uses urban infrastructure to manage rainwater, which is designed to behave like a sponge. Our goal is to incorporate solutions found in nature to address water management issues in urban environments.

Figure 4: Example of a Sponge City in China

Other works similar to our model include the vertical farming technique, prominent in rural agricultural areas. Estimates predict that vertical farming consumes up to 95% less water than traditional agriculture (Parameswari et al., 2024), so even if Xylobench is not implemented to the same scale and detail as on farms, its similar water transport system alone should conserve significant quantities of water relative to traditional watering techniques. Our XyloBench model will include a vertical means of feeding water directly to plant roots, but to accommodate the visual needs of our urban consumers, water will not be transported upward within an enclosed central core, but through multiple vein-like pumps to each plant. This web of veins will be modified to mimic branches on trees or other botanical designs. At the same time, our model will include a reservoir to store recycled rainwater, which will simultaneously function as a typical seating bench outside. This bench and any accompanying electronics will be stored as extensions of the wall of veins on the ground level. All data about the plants' health recorded by the sensors will be transmitted to a dashboard center for viewing, but only key and relevant information will be presented to users to visualize trends over time. Here, account owners can also adjust settings to grant permission to maintenance staff and other users to access operational data about XyloBench. Though this model is bulkier than a typical vertical integration farming unit, its design is tailored for community usage in urban spaces with both aesthetic and water conservation functions in mind. We recognize the current complexities of the software and tracking system, and we are looking to simplify it as we commercialize the product in Phase 2.

HARDWARE SPECIFICATIONS

The XyloBench prototype is a smart rainwater system that integrates storage, filtration, and irrigation within a compact and scalable design. Built with both function and environmental impact in mind, the hardware has been carefully selected and designed to be lightweight, cost-effective, and scalable. Each component plays a critical role in ensuring that the system not only works efficiently but is also easy to replicate and maintain.

The core structure of the prototype is divided into two primary structural components: a horizontal base unit and a vertical wall display, both serving a critical functional purpose in the overall system. The base unit (unit 1) houses the main water management components, including a pre-filtration water container, the filtration system, an acrylic water container, and an external pump. The housing for the main water components is constructed from 3D-printed PLA (Polylactic Acid), assuring that the housing is durable, lightweight, and biodegradable, chosen to reduce cost and environmental impact while ensuring ease of replication. At the core of this base is a transparent acrylic reservoir, which allows users to monitor the water level and quality in real time visually. This reservoir gathers water from the rainwater collected via an opening at the top of the housing. Rainwater first enters a perforated metal mesh, which prevents debris such as leaves or rocks from entering. The water then flows through a gravity-fed filtration system, where large particles and contaminants are removed. Because rainfall can sometimes occur at a faster rate than the filtration system can handle, an additional pre-filtration buffer container is placed before the main reservoir. This ensures that excess water is temporarily held while waiting to pass through the filter, preventing overflow and system flooding. After filtration, the clean water enters the main acrylic container, which is then ready to use.

Water is distributed through a small, non-submersible pump, placed outside of the water reservoir, to prolong its operational lifespan. The pump draws water through a connected inlet tube and sends it through an outlet tube to a network of PET (Polyethylene Terephthalate) tubing. These tubes run vertically up the wall structure, delivering water to the individual plants housed in small containers on the vertical wall. The tubing is secured to the wall using U-shaped clamps and screw-in cable brackets to prevent the plants from falling. This wall holds three individual plant pots that are mounted onto the wall using L-brackets, with each pot receiving water from the pump-fed tubing system.

Next to the bottom base unit, there is another attachment, which is a housing for the electronics (unit 2). All electronics are housed in a weatherproof 3D-printed box made from PLA, sealed with silicone gaskets to protect components from moisture and environmental wear. It also integrates basic smart functionality via several sets of embedded sensors. A rain sensor initiates the filtration process during rainfall, while water level sensors monitor reservoir capacity to prevent overflow. (While the overflow mechanism will not be included in the prototype, it is a critical component that will be integrated into the full-scale bench design in the long term to ensure proper water management and system efficiency.) Soil moisture sensors installed in the planter containers help regulate irrigation, which ensures plants receive only the water they need. A 9V battery (connected to a voltage regulator) will also be located within the housing to provide power for the many sensors.

Each design choice has been made using low-cost, low-waste materials like recycled plastics, acrylic panels, and 3D-printed components. These materials are all selected to ensure accessibility, scalability, and reduced environmental impact. The layout and placement of each element have been chosen to demonstrate efficiency and clarity.

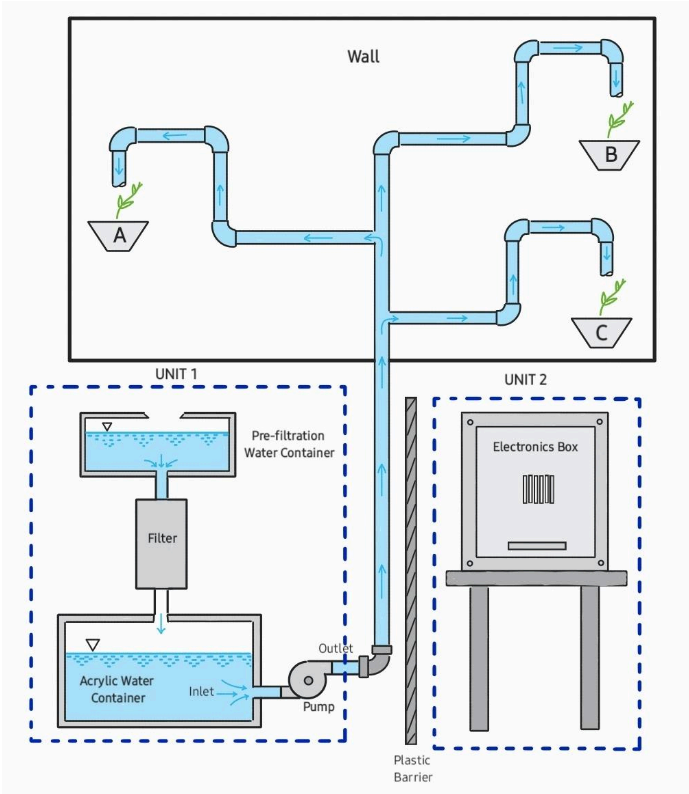
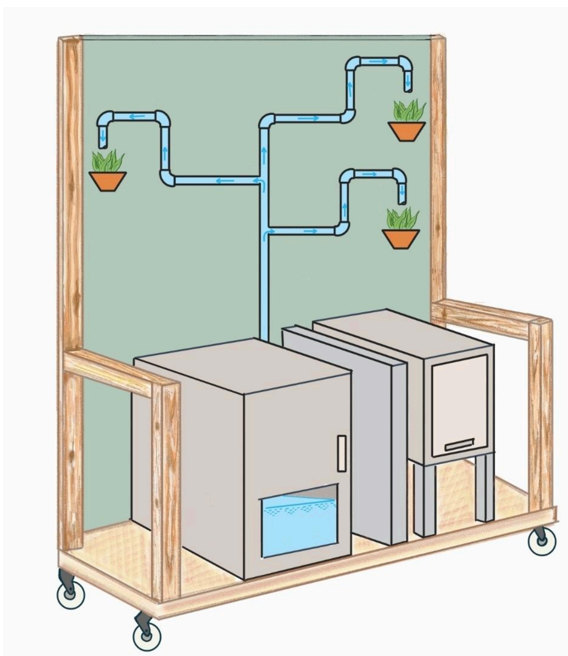


Figure 5: Unit 1 houses the water-related components, including the pre-filtration water container, filter, acrylic water container, and pump. Between Unit 1 and Unit 2, we will install a plastic barrier that serves as a wall to prevent any water from reaching the electronics box. Unit 2 has the electronics box, which will be elevated on a stool to keep it safely above any water that may be on the floor.



Final prototype design of the XyloBench system. This layout demonstrates how all core components connect, featuring a supporting frame for added stability and ease of transport during setup and demonstration.

SOFTWARE SPECIFICATIONS

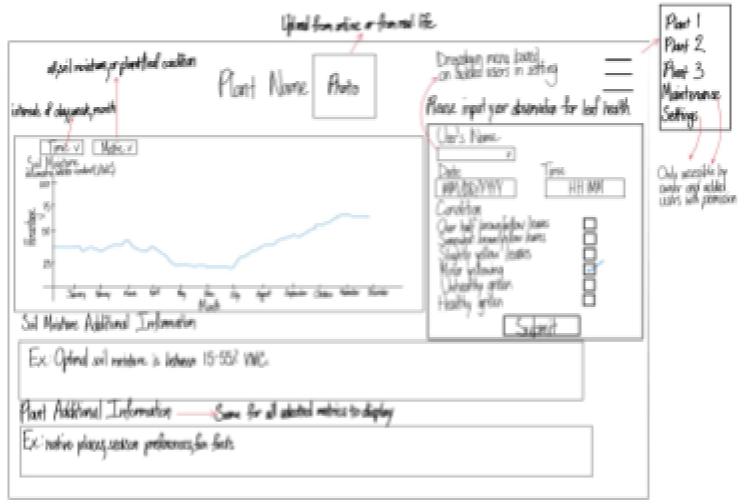


Figure 6: Example diagram of what a user might see on the XyloBench platform

Figure 7: Another example web page of the platform for bench maintenance.

XyloBench offers an easy-to-use web platform accessible from any device through a web browser, allowing users to monitor plant health indicators such as soil moisture and water reservoir levels in real-time in a clearly displayed manner to help users stay informed of their bench. In addition to this, the system automates watering based on this data and personalized watering preferences set by the user on the platform, ensuring plants receive the right amount of water while conserving resources and reducing manual effort. In order for full flexibility, individuals may also manually control watering through the platform whenever they choose. Since sensor data is collected regularly, users can view historical trends and patterns through easy-to-understand graphs, helping them make informed decisions about plant care. Furthermore, the cloud-based architecture of the platform allows it to scale easily, supporting multiple benches and additional features as the project expands or adapts to new community needs.

Once the bench is installed, the user does not need to set up or manage anything. All software operations, including data uploading, system updates, and troubleshooting, are handled entirely by our team through a secure cloud platform. Users will never interact with any backend services or any technical configuration. The system runs automatically, so users can simply enjoy a smart, self-managing irrigation experience with zero technical effort required.

For any questions about XyloBench's system and simple troubleshooting, we plan to provide a dedicated support page with frequently asked questions (FAQ) and other key resources. Beyond the FAQs page, we aim to foster a community-based support model by encouraging early users to share feedback, report issues, and help one another navigate any challenges that arise. This approach will not only help us better understand individual customer needs, allowing our team to provide more personalized support, but also empower users to collaboratively resolve issues and strengthen the XyloBench user community.

To further enhance the user experience, the platform will also offer timely alerts and notifications, such as when water levels run low or a hardware issue is detected, allowing users to stay informed and take simple, guided actions only when necessary.

Behind the scenes, XyloBench operates through a network of connected sensors and cloud-based services designed for reliability and efficiency. Every few minutes, the bench collects environmental data using sensors integrated with a low-power ESP32 microcontroller. This data is securely sent to the cloud, our remote servers, where it's processed to power real-time updates on the web platform and drive automated watering decisions based on user-defined thresholds. All system logic and programming are handled entirely by our team, requiring no technical knowledge from the user.

The system includes backup protocols to ensure continued plant care even during connectivity issues (see Identification and analysis of potential risks/concerns for full details).

Depicted below is a diagram of the software and cloud tools planned for this project, including Amazon Web Services (AWS), a scalable cloud platform used to host our application, manage data, and facilitate device communication; FastAPI, a lightweight backend framework for handling sensor data and user commands; and messaging protocols like MQTT and HTTP to ensure reliable communication between the bench hardware and cloud, while enabling secure user interaction through the web interface. Key AWS services include IoT Core for microcontroller communication, DynamoDB for sensor data storage, EC2 for maintaining continuous platform operations, and Amplify for hosting and delivering what users see on the web page. Together, these tools create a seamless flow of data between the bench and the user, enabling a responsive, intelligent plant care experience.

We recognize that both the hardware and software in the current design are complex and require significant monitoring. Many of these features were included based on our team's technical background and experience; however, as we move toward Phase 2 and eventual commercialization, we plan to simplify both the hardware and software to create a more consumer-friendly, accessible product.

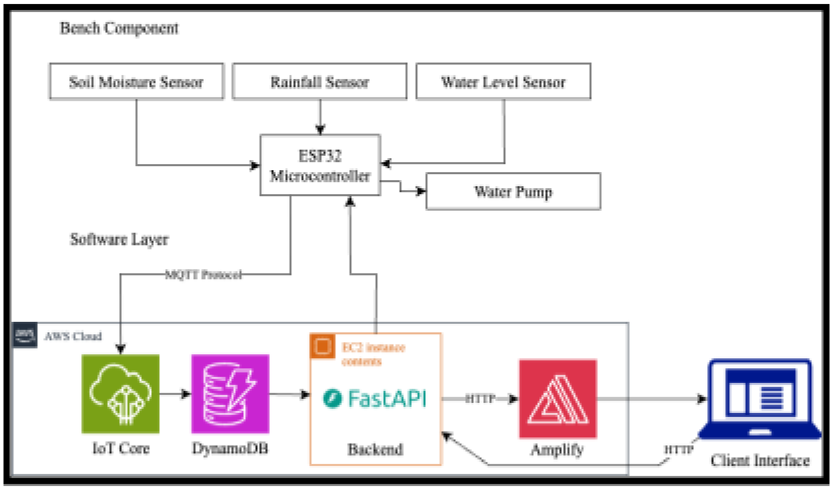


Figure 8: Technical diagram showing software architecture

EXPECTED IMPACT

SHORT TERM

In the short term, we aim to design and build a functional prototype of the XyloBench, a system that harvests rainwater, filters it, and redirects it for the community to reuse. The goal is to demonstrate how small-scale infrastructure can address the problems of water scarcity and can be converted into a tool for environmental sustainability. By using cost-effective materials such as 3D-printed components, recycled plastics, and tubing systems, we intend to showcase a working model that highlights the potential of the prototype in real-world applications. By integrating sensors, this provides real-time data on rainfall, soil moisture, and water levels, allowing the system to adapt to environmental conditions. This introduces a layer of smart technology that empowers users to monitor and learn from the data.

By placing the XyloBench in urban housing communities, this prototype acts as a demo to communities about water conservation while sharing with them the importance of collecting and reusing local rainwater. It becomes a tool that helps people understand where their water goes and how it can be better managed. As rainfall collects in the bench's reservoir and is filtered and routed to the plants, communities gain an understanding of rainwater reuse. This creates engagement with sustainability, especially in cities like those in California that are dealing with increasing water stress and urban runoff.

XyloBench is designed not only to collect and reuse water but also to address urban overflow, a persistent issue in many metropolitan areas. Rather than allowing rainwater to be lost through storm drains or contribute to surface flooding, XyloBench captures and filters excess rain and either distributes it to plants or diverts it into temporary containers. Even at this small scale, it demonstrates how green infrastructure can reduce the burden on public drainage systems and take a step toward local groundwater replenishment.

LONG TERM

While our prototype starts small, in the long term, our project aims to do more than conserve water. At its core, XyloBench tackles a critical issue: urban water waste. One of the most persistent problems in dense, paved environments like apartment complexes and urban housing developments is overflow. Where excess rainwater floods walkways, overwhelms city drains, and ultimately becomes runoff, lost to oceans and never reused. The reality is that climate change is making water scarcity more severe, especially in places like California. By investing in infrastructure like XyloBench, cities can take proactive steps toward climate adaptation by designing public spaces that conserve, recharge, and educate.

Our proposed solution addresses this through artificial groundwater recharge, tailored specifically for urban communities. In community-based apartment complexes, this smart system could connect to community-wide water storage tanks or reservoirs. As water is collected, filtered, and overflow is detected, our system can direct clean, excess rainwater into a larger shared container. It will be located either below ground or in an accessible utility zone within the complex. This container would act as a localized storage unit for all filtered rainwater gathered from nearby XyloBenches.

To ensure that the XyloBench doesn't overflow and continues to work efficiently, we plan to incorporate a smart overflow diversion system. This system would be designed to monitor the reservoir capacity using a flow sensor. Once it reaches a predefined threshold of 90% it will automatically trigger an overflow valve. This valve will redirect the excess water into a secondary container, where it will allow safe and sustainable storage of surplus rainwater. This will prevent urban flooding, maximize water usage, and preserve infrastructure. For a ground-level storage tank, to optimize energy efficiency and reduce dependency on powered systems, we propose using an indirect pumping system, where water floats within the tank, and once the outlet is opened, gravity helps pull the water downward and outward. This pressure-dependent system allows water to be pulled with or without electricity, making it highly reliable during outages or in low-resource environments. The hardware in the container is tightly integrated with software that gathers real-time data from the sensors implemented, which informs the system's behavior. Such include sending alerts when action is needed, tracking monthly water capture metrics, and logging maintenance requirements. To ensure the longevity and sustainability of the tank itself, we propose using glass-lined materials, which are durable and rust-resistant despite constant exposure to environmental elements. The durability of this material guarantees a long operational lifespan while also requiring low maintenance and associated costs, making it a sustainable solution for municipalities or housing communities.

Even though the system will be designed to work autonomously through the use of sensors, pumps, and automated overflow management, routine maintenance is required to address any potential malfunctions. A trained system administrator or technician would have to do a monthly service check to perform a routine inspection to check the condition and performance of sensors, check pumps for signs of mechanical wear or blockages, clean or replace filters as needed, and assess the condition of the reservoir and tubing to prevent the buildup of biofilm or debris. This technician could be someone with general experience in plumbing and electronics. In residential settings, maintenance could be managed by the building’s facility. The technician fees would be covered through the tenant's maintenance charges or the property’s operations budget. This could be part of the existing landscaping or groundkeeping contract. For public installations, this would fall under city departments such as Parks & Recreation, where the costs are funded through municipal budgets, environmental grants, or public-private partnerships. The cost would be small since the technician would only be required 1-2 hours per month. The system has been purposefully engineered to require minimal maintenance while at the same time remaining user-friendly, adaptable, and straightforward to repair over time.

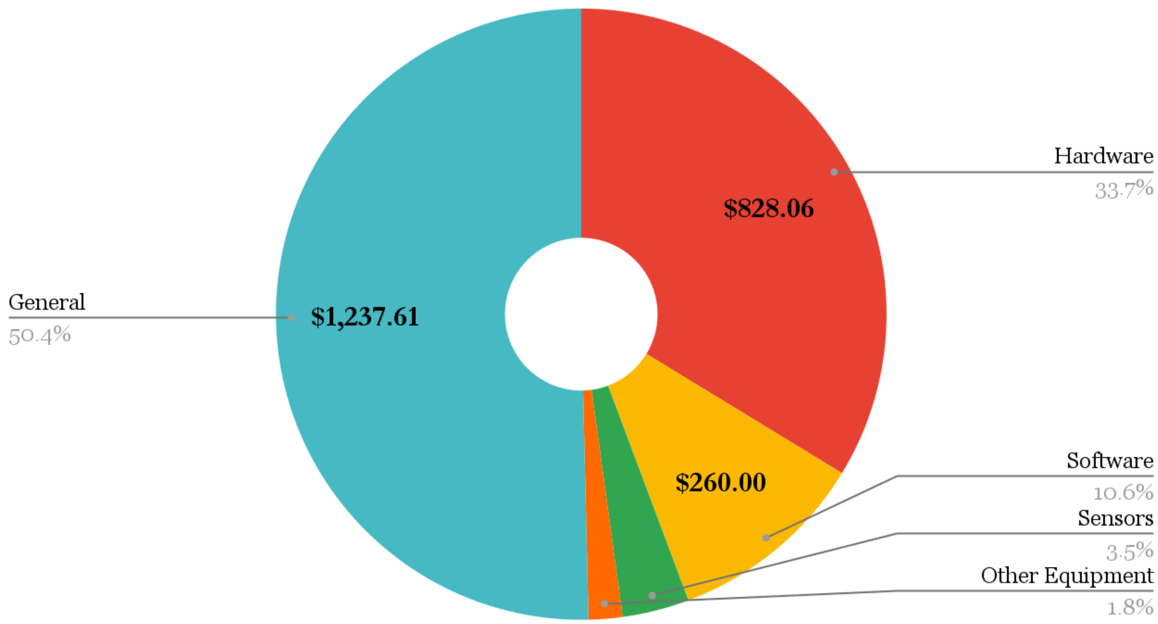
If both the primary and secondary containers reach full capacity or if the system experiences sensor failure, software issues, or power outages during storms, an emergency backup plan will be activated. This includes a tertiary fail-safe system where a final emergency outlet will guide any excess water toward a permeable surface located downstream of both the main routing system and the community storage tank. To ensure effective infiltration and prevent surface pooling, it’s important to think about the type of soil it will be placed on. Soil porosity, permeability, and composition impact how efficiently water is absorbed and filtered back into the ground. Before installing anything, we would need to run basic soil tests, like infiltration and percolation tests, to determine whether the ground can handle the water. The ideal kind of soils that would be best suited would be sandy loam, loamy sand, or gravel-based soils, which offer high permeability. Heavy clay or compacted soils wouldn't work since water tends to sit on top instead of soaking in. To help with drainage and also prevent clogging, we’d also include a gravel layer. This extra layer will act like a filter and make sure that water moves smoothly through the soil. Additionally, rather than relying on a single overflow path, we’re thinking of splitting the flow: approximately 90% of excess water would be directed to the storage tank, while 10% flows directly to the permeable bed for passive groundwater recharge.

To further strengthen the system, a manual override feature would be included. In the case where the sensors or pumps stop working, a trained technician would be able to manually operate the valves, pumps, and overflow controls. This ensures that water can still be managed if any of the components fail. This fail-safe feature is crucial to preventing damage from overflow or system failure and adds an extra layer of security to the design.

To address the potential challenge of the rainwater reservoir running dry due to evaporation or inconsistent rainfall, the system will include a manual refill feature. This ensures that the automated watering continues uninterrupted, even during dry periods. Residents will have the option to pour leftover water, such as unfinished water bottles, directly into the bench through a designated opening inlet. This not only keeps the system running but also encourages water reuse in everyday life, reinforcing sustainable habits. To further support the system’s longevity and minimize water loss, the long-term design that will be constructed from concrete will have a UV-resistant coating. This protective layer helps prevent surface degradation from prolonged sun exposure, minimize discoloration, and reduce water absorption. By sealing the structure with a UV-stable concrete sealer, the bench will maintain its appearance, while also helping limit evaporation from exposed water components. These strategies will improve performance, reduce maintenance needs, and promote a more resilient and sustainable design.

By preparing for the unexpected, we’re building a system that cities can rely on to build a more sustainable and water-conscious future. Over time, we can implement XyloBenches across public parks, transportation hubs, and commercial spaces that can contribute to decentralized groundwater recharge infrastructure. Each bench will act like a small but essential part of a larger network, redirecting clean, filtered water back into the ground, replenishing aquifers that cities and agriculture depend on. With smart routing, overflow can be channeled to local percolation zones, recharge pits, or even scaled up to connect with municipal efforts. Additionally, we see the potential to collaborate with private landowners, apartment complexes, and housing developments through incentivized partnerships. Offering benefits like discounted water rates or tax breaks in exchange for participation in local recharge efforts. This community-level involvement makes the XyloBench system not only a tool for sustainability but a gateway to greater water equity and resilience.

Figure 9: Total Cost Breakdown



BUDGET PLAN

While a detailed breakdown of our budget proposal can be found here, the chart above summarizes the general allocation of our expenses, with slightly over $1,000 of our budget devoted to physical materials for the construction of our prototype and the remaining money to general expenses like travel fees and a buffer fund in case of accidents. Since our webpage will be built online, software expenses are expected to be relatively cheaper than the hardware side, with only expected costs for cloud storage software and licensing access to web tools. Throughout the project, AWS's free tiers will suffice in creating a singular prototype. However, for a full deployment supporting 15-20 benches without free tier benefits, we estimate $200 for upfront AWS costs and around $20 in monthly fees, giving a cost of roughly $1.50-$2.00 in monthly software fees per bench for customers. Furthermore, the current prototype avoids concrete and other bulky materials for the sake of presentation, but the addition of these materials to the final product for sale is expected to raise the sales price to about $1,500 to $2,000 per bench.

Beyond initial design and creation costs, customers may also be concerned about long-term maintenance and operational expenses estimated at $656.16 annually to hire technician staff for regular check-ups and support cloud services. We do expect minor upkeep to be necessary every month and major changes like pump replacement to occur every few years, so regular technician checkups are important in identifying and correcting problems before they turn serious. On the other hand, users are recommended to regularly log in to the webpage to input data about leaf conditions and plant health that can not otherwise be recorded through sensors. This will come at no cost to the user, but will require some time commitment. As we reevaluate the hardware and software changes, we hope to bring the costs of the bench and maintenance down to a more economical amount that is affordable for the community.

RISK IDENTIFICATION AND ANALYSIS

To ensure that the project is functional before the competition and for the long term, the team must identify potential risks that may hinder progress. The team decided to focus on four main categories: mechanical, hardware, software, and operations, which were selected based on urgency and overall impact to the project. Risks are labeled and organized onto a Risk Matrix, shown in Fig. 10, based on how likely the risk will occur and how severe its impact will be to the project. This is all graded on a scale from one to five, with 'one' being of the lowest concern, and 'five' being of the highest concern.

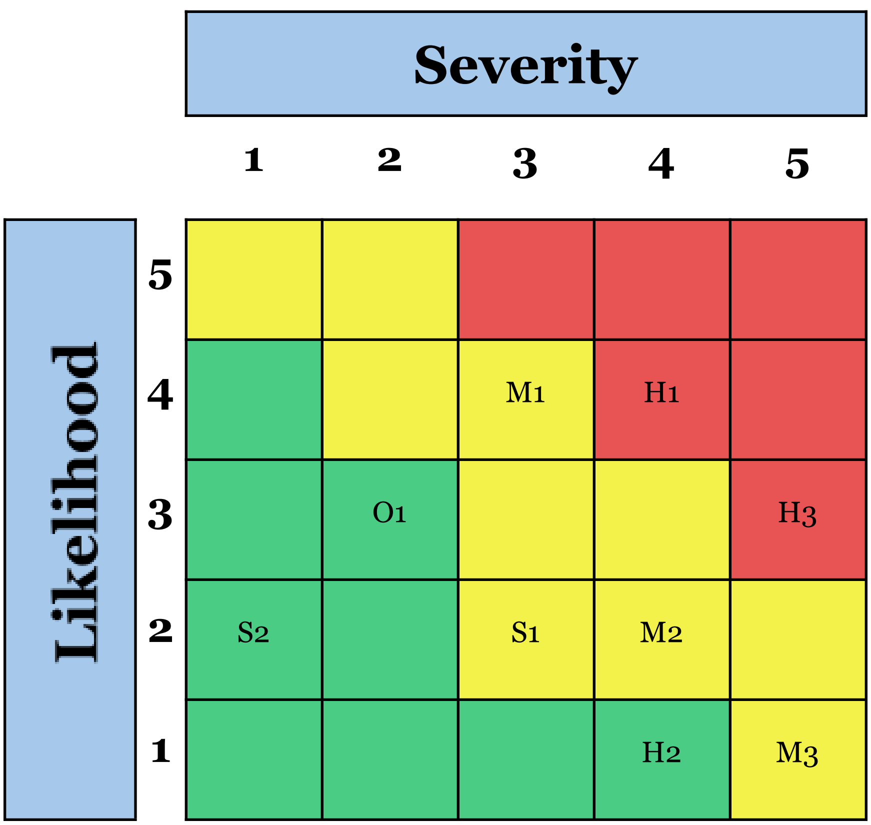


Figure 10: Risk Matrix

MECHANICAL

The project will introduce problems when working with water treatment and distribution methods. Another anticipated risk is the clogging of filters and pipes (Risk ID: M1). Heavy rain and runoff streams can carry leaves, sediment, and bacteria into filters and pipes, which can consequently cause water flow to be impeded (Why Are Your Water Filters Clogging So Fast, 2024). Some mitigation strategies the team has devised include placing a grill to stop larger objects from entering the tubes, occasional pipe cleaning, and filter replacement when needed.

One major concern involves leakage from the ends of the water pipes due to high-pressure flow of water or structural instability (Risk ID: M2). This can be problematic as it can loosen the pipes over time and spill water, and potentially damage the electronics that are near the leak. The team has implemented mitigation strategies to reduce this occurrence, such as using washers and clamps to secure the pipes and their ends. Likewise, the team will use a mixture of PVC and PET tubing, materials that have good strength and stability to handle water.

A major concern identified is the failure of the system during harsh weather conditions (Risk ID: M3). In seasons when heavy rain is frequent or heat is unforgiving, it can overwhelm the water line and cause potential leakage and damage to pipes. In addition, plants are also at risk of root rot from too much water (Hill, 2023) and burn from the blazing heat. The likelihood increases depending on seasons such as spring or summer, and will be consequential if not mitigated. Therefore, the team has brainstormed a few ways to circumvent this issue. Firstly, creating a permeable bed for the overflow of water will help redirect excess water into the underground ecosystem. Likewise, applying a mesh or film to cover the plants will help minimize sunlight exposure on hotter days and deflect some rain during rainy seasons.

HARDWARE

Considering that the electronics will be stored outside within a custom enclosure, it is important for the team to account for California's weather conditions in the hot and rainy seasons. Overheating (Risk ID: H1) is a prime risk for the components since the box will be subjected to intense heat under the sun for prolonged periods. This can inevitably lead to overheating and permanent damage to parts, and require frequent replacement. To mitigate this issue, the team plans to design an enclosure that allows ventilation for air flow and uses white paint to reduce absorption of heat.

Due to the many sensors, pumps, and components, enough power must be supplied to the circuit. However, due to the possibility of overheating, voltage overdraw, or an aging power source, the battery may not be able to handle the power load needed (Risk ID: H2). This can cause the system to underperform, components such as sensors to fail, and even damage components if not enough voltage is supplied. It is imperative that a robust power supply is selected to meet all the requirements of all parts. Likewise, a backup power supply may be necessary in the chance that the primary power source fails.

A massive risk that may endanger the system overall is if moisture ever enters the enclosed electrical circuit (Risk ID: H3). Due to its proximity to the water pump and water tank, there is a potential chance of water entering the enclosure, which can permanently fry and short the electronics if not properly insulated. Based on how severe the problem is, the team plans to isolate the electronics in a separate housing that is waterproof, while attempting to minimize areas where water can enter. Likewise, some sensors will be used in liquid environments, so exposed wires and PCBs will be insulated in a waterproof but also nonconductive material.

SOFTWARE

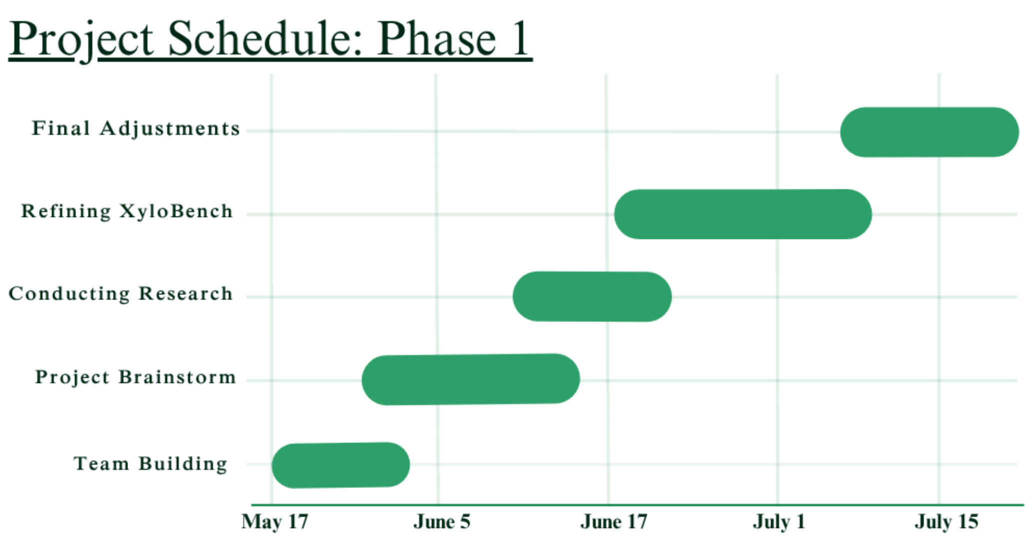
The project uses many electronics, such as microcontrollers, sensors, pumps, and power sources, that come with potential risks. One major risk involves inconsistent readings of sensors (Risk ID: S1) due to a variety of factors such as environmental effects, a faulty product, or incorrect installation. This could possibly reduce the effectiveness and even functionality of the sensor, which would cause issues with monitoring plant health and possibly require the sensor to be replaced soon. To mitigate the risk, it is advised to research sensors best suited for outdoor conditions, how accurate it is, and robustness at the price point. Likewise, the team needs to verify wiring of components is properly done through multiple hardware testing cases.

Another risk (Risk ID: S2) is the possibility of connectivity failure and network loss due to external signal interferences or hardware failure. Consequently, data will not be received and would prevent the system from being able to respond to different environmental conditions. To mitigate this issue, the team plans to implement software safeguards to protect the data whilst retaining the system's core operations. The system includes backup protection to keep your plants safe even when internet connectivity is interrupted. If the bench can't communicate with our cloud servers, it automatically switches to local operation mode, continuing to water your plants based on sensor readings until connection is restored. This ensures your plants stay healthy regardless of Wi-Fi outages or connectivity issues.

OPERATIONAL

In addition to the many risks identified previously, the project can be accompanied by other non-engineering risks such as budgeting, time constraints, or organizational problems. One identification of that risk is the possibility of a lack of personnel to maintain the project's system over its long period of use (Risk ID: O1). This may either be caused by unsatisfactory working conditions, such as low pay, poor retention, or negligence from the owner. Consequently, this issue would make it difficult to sustain the project further into the future because the system can break down due to age and wear if not periodically maintained. To mitigate this problem, it is imperative for the owner or organization to hire technicians to perform regular maintenance on the system.

FIRST PHASE SUMMARY



Accordingly, for Phase 1 our team met regularly to brainstorm and refine the XyloBench project. Our work time consisted of team building, where we shared our skill sets and brainstormed, which helped us streamline task distribution for the project. Researching important elements were made individually and shared with the team during weekly sessions. Finally, we participated in meetings with our coaches where they provided feedback to support us on how to improve certain aspects of our project.

TEAM COMMUNICATION TOOLS

The execution of this project started immediately after we received the initial details about this competition. We first set up a Discord server, which was our primary medium of communication together as a group. This server is intended for all types of communication, like meetings or quick updates, and any sort of work we've been doing related to the project via several different channels to better organize our thoughts. A separate tool was used for communication with our coaches: Slack. Not only did it give us an organized and professional way to communicate with our coaches, but it was also a way to get familiar with real industry tools.

Our group met online 1–2 times a week using When2Meet to coordinate schedules with our coach. Early meetings focused on introductions and exploring our skills and interests. Finding a project that connected our diverse disciplines was initially challenging, and we explored multiple ideas before aligning on XyloBench. Open communication and regular feedback helped us converge on a shared vision that balanced sustainability, urban design, and technical feasibility. XyloBench ultimately integrated our strengths while addressing real-world issues of water conservation and urban greenery.

TASK DIVISION AND PROJECT REFINEMENT

After refining the problem of focus and how we planned on addressing it, we began delegating tasks among each other to divide and conquer this project. Initial tasks included researching the problem and the target audience, looking into engineering and software components to implement, and what problems may arise with the initial idea of the XyloBench. Task management was done through Jira, a tool that kept us updated with what we needed to work on, what members were currently doing, and what we had finished. This streamlined our workflow and kept everyone aligned and productive throughout the planning phase.

To keep track of all our notes and research, we utilized a shared Google Drive that served as a repository for the whole group to add their completed task work. Key items in this repository included our weekly meeting notes, research findings, and all things planning about our project. This also served as a way for coaches to review our work and provide necessary feedback on any item we've worked on, which helps us iterate on XyloBench designs and other technical aspects.

We used AI tools throughout the project to support ideation and refinement. Specifically, we leveraged ChatGPT to analyze the feasibility and impact of our initial concepts, helping us evaluate trade-offs between sustainability, technical complexity, and user value. It also assisted in exploring design alternatives, generating use-case scenarios, and improving our written communication and documentation. While AI didn’t directly drive any core technical component of the XyloBench, it played a valuable role in accelerating decision-making, clarifying complex ideas, and enhancing the overall quality of our planning and presentation.

SECOND PHASE PLANS

As we move forward in this competition and into Phase 2, our team will be splitting into designated sub-teams and meeting frequently for interdisciplinary check-ins. To ensure steady progress, each sub-team will focus on key technical milestones. The software team will work on streamlining data processing and system integration, while the hardware team will refine the physical design and ensure compatibility among components. Alongside technical development, we'll be simplifying both hardware and software to reduce complexity and lower production costs. This includes reevaluating our cost structure, minimizing maintenance needs, and determining a more realistic purchase price to make the final product more accessible and appealing to customers. Meetings are structured around solving these challenges and aligning all components toward a fully functional and market-ready prototype.

The structure of our tasks in Phase 2 will be organized through a Gantt chart, which is a visual project management tool that uses bar charts to illustrate the project's schedule as well as the sub-teams' and individual growth throughout the months. This will support us with accountability of tasks and on individual deadlines in order to have a successful Phase 2. Finally, Helen will introduce the team's Phase 2 Gantt chart as soon as the deliverable one has been submitted.

PROTOTYPE NEXT STEPS

XyloBench was developed in response to growing concerns around urban water waste and the limited access to greenery in high-density environments. Our solution targets shared community spaces in urban areas by introducing a smart, sustainable bench that not only conserves rainwater but also promotes environmental awareness. With its modular design and integration of both hardware and software technologies, XyloBench has the potential to improve community well-being while supporting long-term urban sustainability goals.

As we move into the next phase of development, a key focus will be refining our design with guidance from subject matter experts to ensure it is both effective and affordable. We recognize the challenge of making XyloBench accessible to low-income urban communities and will actively explore potential partnerships with specialized organizations and funding sources to facilitate seamless integration into these areas. In parallel, although we've briefly mentioned practical long-term considerations, such as durability, maintenance, and outdoor performance, we will continue the discussion on these factors to ensure the product remains viable and sustainable in the environments it's intended for. In terms of development of the prototype, we'll start ordering key hardware components like sensors and microcontrollers, while also looking into lower-cost alternatives to keep the system accessible. We'll continue using the organizational tools that helped us stay on track in the first phase to keep things running efficiently. With a solid foundation and a clear next step, we're excited to keep building XyloBench into something both impactful and practical for communities that need it most.

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