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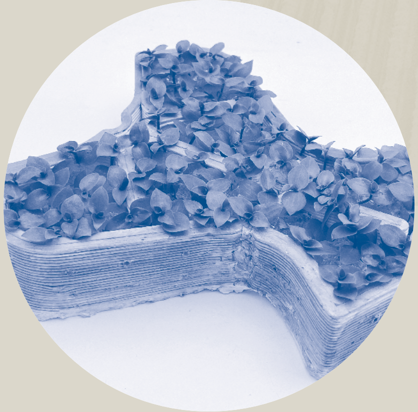
SimbioBrick II: Portable Bioremediation Technology for Urban Farming and Environmental Justice



MARCH 2026

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Kleinman Center
for Energy Policy

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The Fishtown Case

Philadelphians suffer pollution stemming from a long history of urban industrialization from a myriad of relic industrial sites since 1956 including smelters and processors along the Schuylkill River (Figure 1a). Sites occupied by industrial remains increase the residents' exposure to heavy metal pollution, especially to lead in soil and air when construction developments take place in the active sites. Soil sampling has shown that Fishtown has the highest lead pollutant concentration among all areas in Philadelphia (Conway 2020; O'Shea et al. 2021; Purcell et al. 2017) (Figure 1b).

In addition, the lack of tree canopy protection results in urban heat island effects, and the number of cars in surrounding highways in poor air quality with volatile organic particulate matter derived from tires and exhausts (Figure 1c). Affected by urban heat, residents in poorly insulated homes and neighborhoods lacking continuous urban green canopy face significantly higher risks of lung, renal, and cardiovascular diseases (Gronlund 2014; Foroutan et al. 2024). This increased disease burden is linked directly to exposure to extreme temperatures and heightened pollution levels. Prolonged exposure to any type of pollution contributes to children's neurobehavioral disorders, reduced cognitive abilities, and impaired function of internal organs (Kampa and Castanas 2008).

There is an urgent need for policies that prioritize multidimensional ecological justice in proper home insulation, urban vegetation, and comprehensive soil and air remediation in Fishtown Philadelphia and beyond. After focusing on urban carbon capture with SimbioBrick I—described below—soil bioremediation is the target of Penn DumoLab's SimbioBrick II technologies.

Emergent Policy on Urban Bioremediation

Regenerative architecture has recently emerged as a forward-thinking, site-responsive approach that goes beyond reducing environmental harm into actively supporting the renewal of ecosystems, including soils (Mang and Reed 2012). Traditionally, soil has been treated as a background element in architecture, valued mainly for its structural or utility functions—bearing loads, draining water, or storing heat.

This narrow perspective, reinforced by legal frameworks that grant landowners broad rights to modify or degrade soils, has contributed to the disruption or irreversible loss of vital biological and chemical processes in soil ecosystems (Lokko 2025). However, a growing number of contemporary buildings now incorporate soil health as a design priority.

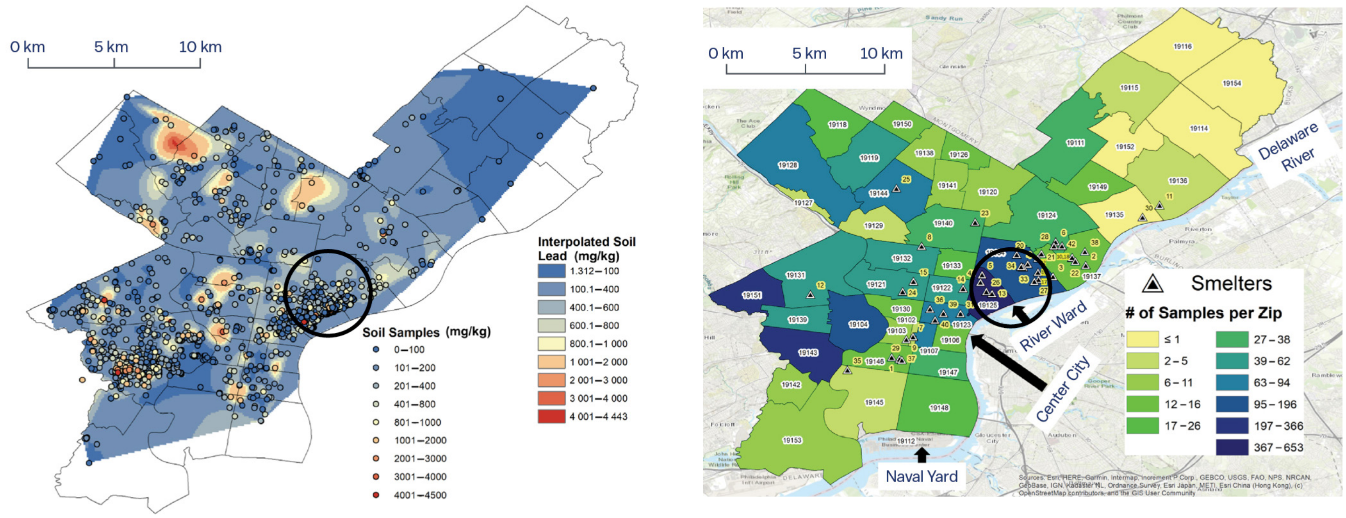
The Bullitt Center in Seattle (The Miller Hull Partnership 2013) exemplifies this shift. It uses composting toilets and a greywater treatment system to minimize reliance on municipal infrastructure while producing soil-building outputs. Similarly, the Omega Center for Sustainable Living in New York (BNIM Architects 2009) uses constructed wetlands that purify wastewater and regenerate nearby soils.

The PAE Living Building in Portland (ZGF Architects 2021) includes bioswales and rain gardens to reduce runoff and erosion, directly improving soil quality. In agricultural settings, the Center for Agroecology at UC Santa Cruz (Fernau and Hartman Architects, 2017) integrates composting, permaculture landscaping, and diverse planting to rebuild topsoil and store carbon—approaches that can inform rural land-use policy.

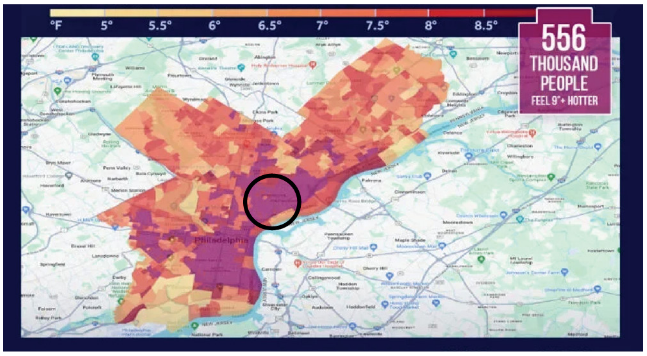
Figure 1: Environmental Data in Philadelphia, PA (Fishtown Area Circled in Black)

(a) Location of Historical Relic Smelters

(b) Soil Lead Poisoning Levels



(c) Urban Heat Island Affected Neighborhoods and Highway Locations



Adapted from (Climate Central 2024; PADEP 2025; O'Shea et al. 2021).

Urban policy can also benefit from regenerative design. In Basel, Switzerland, a mandatory green roof policy has turned rooftops into functioning ecosystems that absorb stormwater and mimic natural soil processes. The Max Planck Institute in Hamburg supports nutrient cycling and biodiversity through green roofing (Sommese et al. 2025). Across Europe, the HuMUS consortium advances municipal soil health. In Roubaix, France, the REVALS project repurposes post-industrial land into community-run ecological farms, with soil quality monitored through local stewardship and data tracking (HuMUS 2023).

These examples highlight the potential for integrating soil health into policy frameworks for building codes, zoning, land ownership rights, and infrastructure planning. Still, more work is needed. Emerging research on bio-based and bio-receptive building materials suggests that architecture itself can function as a regenerative tool for soil restoration, encouraging policies that promote the integration of living materials and ecological design strategies in the built environment to actively rebuild soil health and biodiversity.

For example, incorporating mycelium composites and hempcrete in construction can create biodegradable structures that return nutrients to the soil at end-of-life. Similarly, bio-receptive concrete façades and green roofs can host mosses, lichens, and microorganisms that enhance local micro-ecologies, sequester carbon, and stabilize degraded soils.

Urban planning initiatives could further incentivize permeable pavements, living walls, and biologically active building skins that filter rainwater, foster microbial diversity, and support natural soil regeneration cycles. Policies that encourage these innovations—through funding, standards, or regulatory reform—can help scale regenerative practices and ensure long-term ecological resilience.

Portable Tech as Hyper-local Bioremediation

Our SimbioBrick research pushes forward a transformative innovation demonstrator to influence policy that can go hand in hand with a fair transition framework in bioremediating landscape and architectural practice serving local communities. Demonstrators in bio-based and bio-receptive building strategies can play a pivotal role in influencing policy by providing tangible, data-driven evidence of how regenerative design can restore ecosystems while meeting architectural and social needs. These real-world prototypes—ranging from experimental mycelium pavilions and algae façades to soil-regenerative urban installations—serve as proof-of-concept models that policymakers can observe, measure, and evaluate.

By showcasing quantifiable outcomes such as soil microbiome recovery, carbon sequestration, stormwater retention, and reduction of construction material's toxicity, demonstrator projects help policymakers translate abstract sustainability goals into measurable environmental performance criteria. This empirical evidence can inform new building codes, green certification standards, and public funding programs that prioritize materials and methods proven to regenerate rather than deplete natural systems.

Furthermore, demonstrators situated within public spaces, academic institutions, or municipal projects create visibility and public engagement, generating cross-sector collaboration among architects, environmental scientists, and policymakers. This collaboration can lead to policy innovation, such as incentivizing circular material economies, mandating life-cycle soil impact assessments, and integrating bio-receptive design into national climate adaptation frameworks.

We target Fishtown sites first because of our Penn team's local expertise, available vacant lots, and history of low greenery and industrial pollution affecting the community now.

Part of our research focuses on devising living and sustainable alternatives for living green walls. Green walls are increasingly recognized as an effective carbon offset strategy, as they capture atmospheric carbon through plant-based photosynthesis (Shafique et al. 2020).

However, current implementations often involve resource-intensive construction, reliance on unsustainable materials, and significant ongoing maintenance costs. These limitations have spurred new research into wall systems that utilize multifunctional living materials or life-supporting materials. Such innovations aim to reduce environmental impact, lower construction and maintenance demands, and support policy objectives related to sustainable urban development and climate resilience (Sandak et al. 2019).

Our work contributes to this research in experimental devices for urban bioreceptivity and bioremediation such as a reconfigurable ecologically sensitive structural cement walls (Bearak et al. 2008), digitally designed macro-porous surfaces and tiles from modified concrete to enable algae and moss receptivity (Cruz 2022), printed ceramic walls for potted plants with inner biophotovoltaic energy harvest (UrbiNat 2022; IAAC 2020), or passive rain biofiltration gels coated into urban ceramic tile towers (Mendez and Chapa 2021).

Technologically, SimbioBrick defines portable fungi-plant living brick systems supporting greenery, bioremediation and urban agriculture. Bricks have formats that span architectural and ecological scales in vertical gardens, soil improving pavements, healthy play structures, and vertical food farming, and maximize green canopy, carbon sequestration, soil pollutant trapping, and oxygen production.

Development of SimbioBrick I & II

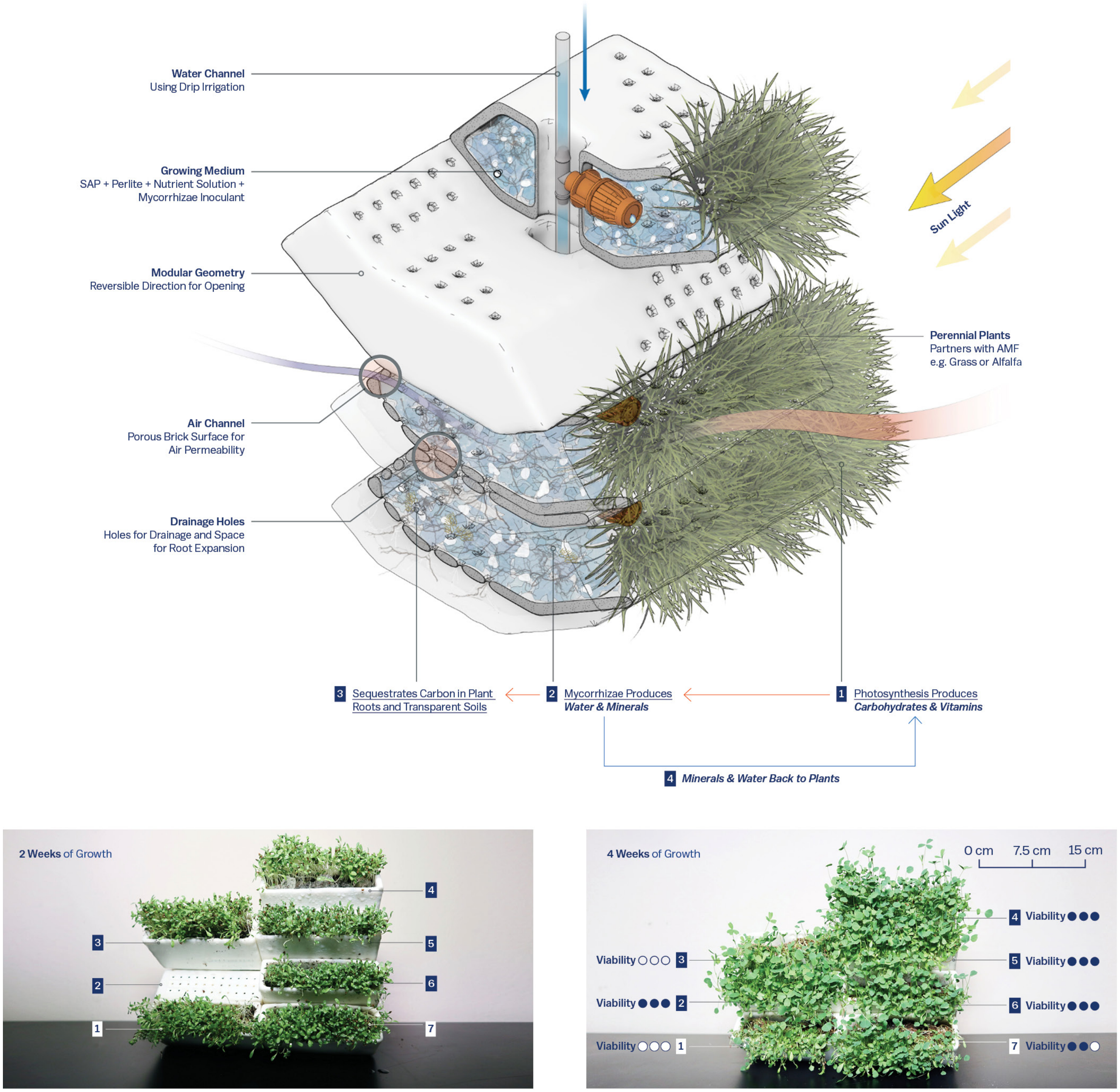
SimbioBrick merges three fields of contemporary research in bio-receptive architecture, modular façade construction, and material-informed design. To facilitate translation from biology to technology, we first delved into biological response-driven design processes across scales in SimbioBrick I (Bae et al. 2024). The 2023–24 development phase focused on designing a biologically active, modular brick that could support plant-fungi symbiosis as a means of atmospheric carbon sequestration.

SimbioBrick I

In SimbioBrick I, we developed a living brick system that facilitates the symbiotic association between mycorrhizal fungi and plants as a functional mechanism for atmospheric carbon capture (further described in Bea et al. 2024). The design incorporated arbuscular mycorrhizal fungi (AMF) and perennial alfalfa as a partner plant, chosen for its dense and fast-growing root network that increases the likelihood of contact with fungal spores. A fine-tuned growing medium was developed using superabsorbent polymer (SAP) hydrogel, nutrient solution, and mycorrhizal inoculant (Paré et al. 2022). This medium retained moisture, slowly released nutrients, and provided transparency for verifying root–fungi interaction through microscopic imaging.

To support this biological process within a constrained architectural geometry, we iteratively developed a modular brick form with porous surfaces, internal voids, and drainage channels, designed to mediate water flow and ventilation (Figure 2 top). These bricks allowed fungal networks to colonize the plant root without inducing rot, addressing early failures observed in prototypes with poor drainage. In physical tests, alfalfa germinated successfully in all bricks, and units with both mycorrhizal inoculant and porous brick geometries showed improved plant viability and observable fungal colonization compared to control units (Figure 2 bottom). Microscopic imaging confirmed the presence of hyphal networks extending from roots, verifying the establishment of plant–fungi symbiosis in specific configurations.

Figure 2: System Overview of SimbioBrick I (top) and Physical Experiments Validating the Benefits of Fungal Colonization for Plant Viability (bottom)



The integration of biological viability and architectural geometry demonstrated the potential for modular living systems to function as carbon-sequestering building components (Bae et al. 2024). Additionally, the rotatable modular design allowed bricks to be deployed in multiple configurations—as façades, walls, or pavers—enabling both vertical and horizontal plant growth and extending their ecological reach.

The units were fabricated through digital manufacturing processes that allowed rapid iteration and testing, enabling close integration of biological and architectural parameters. Additionally, SimbioBrick I demonstrated the potential for architectural systems to behave as living, carbon-sequestering organisms, integrating environmental performance with material design. Its contribution to the sustainable built environment lies in offering a biologically active alternative to inert, high-embodied-energy façade systems—one that is modular, low-maintenance, and responsive to local climates.

Nonetheless, the first generation revealed challenges: the casing was fabricated using non-load-bearing prototyping grade resins and lacked integrated connections for structural stability allowing larger-scale deployment. These lessons directly informed the innovations of SimbioBrick II, which addresses modular interconnectivity, material biodegradability and strength, and system scalability—further advancing the integration of biological agency into the built environment.

SimbioBrick II

Applying lessons from SimbioBrick I, we developed SimbioBrick II—a multi-functional system in a stronger material to deploy portable bioremediation and urban farming across a series of prototypical sites.

The new unit uses fired porcelain with superior compressive structural capacity (~350MPa) than prototyping resins (~80MPa) in a newly designed form to ensure adhesive free connection and structural capability while maintaining all the features SimbioBrick I presents to be helpful.

In terms of embodied carbon, we estimate that even if firing of clay decreases the overall carbon performance of the system, the advantages of moving away from petrochemical resins and their environmental footprint is important, as is avoiding any derived chemical toxicity from components to existing soils and water resources during use cycle and end of life.

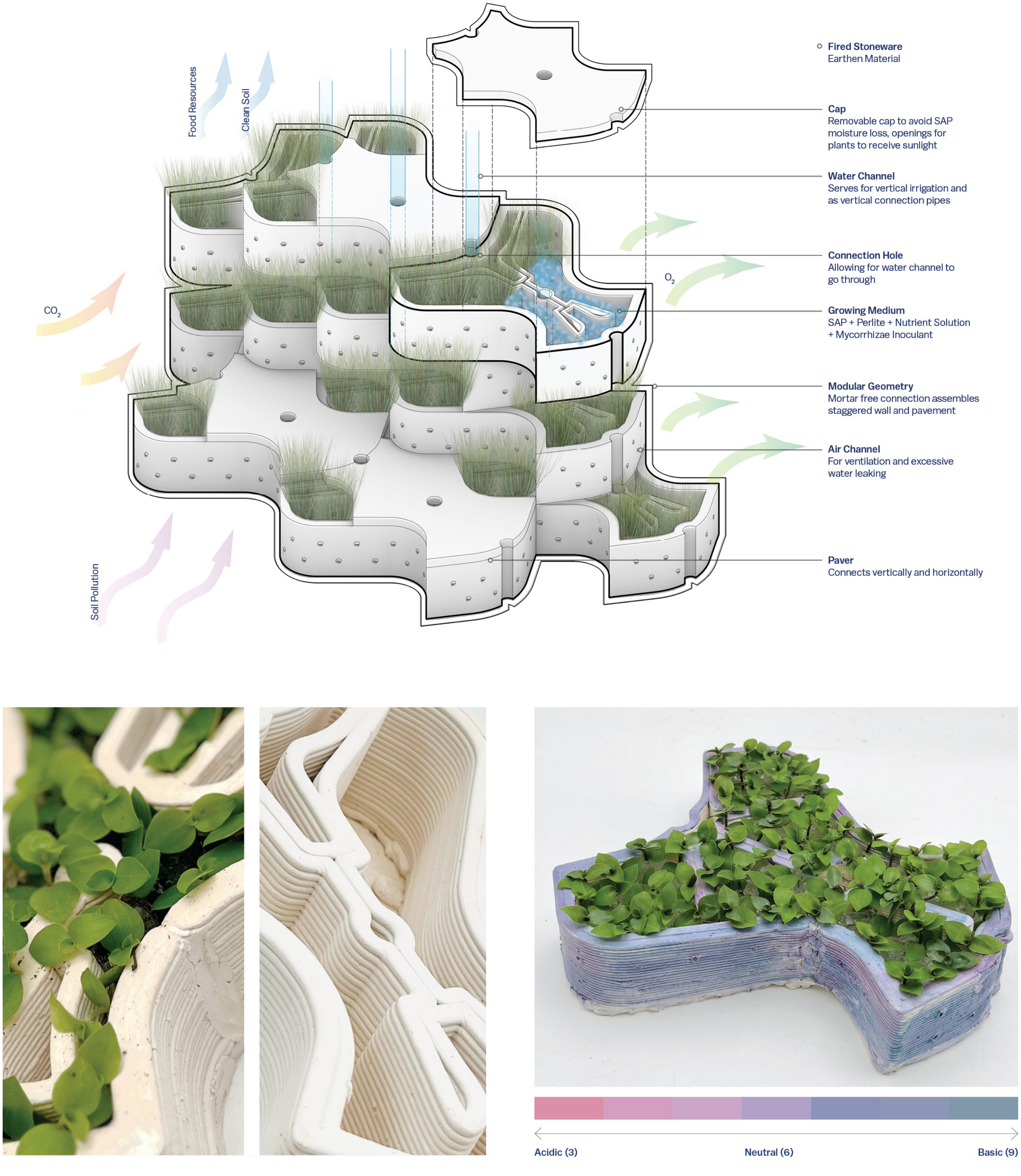
Bricks are additively manufactured (3D printed) from porcelain clay, creating a geometry that complies with the biological needs of the plant–fungi system in terms of shaded depth, drainage, and ventilation. The printability constraints of wet material results in another asset: the ridges double as plant growth cavities (Figure 3 bottom left), while allowing for connection through peg–socket and channeling resulting from ridge-enabled friction (Figure 3 top).

The development process, which focuses heavily on fabrication of the non-living brick casing, also includes testing of clay to water content viscosity, nozzle extrusion sizes and layer amounts, simplified and optimized tool path for clay printing, fired clay preferable thickness for structural capability, connections between brick modules, overhangs, etc.

A layer of natural wax is applied to the inside faces for water retention while ensuring end-of-life degradation without toxicity. SimbioBrick II units can be coated with pH sensing dyes, allowing the potential for sensing soil health levels while mediating the environment (Figure 3 bottom right).

Globally, the system proliferates in different use case assemblies opening possibilities for fencing, vertical wall, paver systems, urban seaters, rainwater storage flooring, vertical gardens, individual plant vases, etc. and it aims to bioremediate, soil, air, and heat. A series of site conditions are developed for Fishtown in Philadelphia connecting the neighborhood's Recreation Center with Penn Treaty Park at the shore of the Schuylkill River (Zhang 2025).

Figure 3: SimBiobrick II as a Portable Proliferating System (top) with Dual Serving Inner Structures Promoting Biological Health and Brick Structural Stability (bottom)



Fired Stoneware
Earthen Material

Cap
Removable cap to avoid SAP moisture loss, openings for plants to receive sunlight

Water Channel
Serves for vertical irrigation and as vertical connection pipes

Connection Hole
Allowing for water channel to go through

Growing Medium
SAP + Perlite + Nutrient Solution + Mycorrhizae Inoculant

Modular Geometry
Mortar free connection assembles staggered wall and pavement

Air Channel
For ventilation and excessive water leaking

Paver
Connects vertically and horizontally

Figure 4: Envisioned Bioremediation Sites in Fishtown (Philadelphia, PA)

(a) Pollution Levels Along Intervention Sites

Highway Neighborhood	
Exposure to Pollution	63rd
Pollution Burden	76th
Child Lead Risk	48th
Sensitive Populations *(population with asthma/cancer/disability)*	4th
Poverty	35th

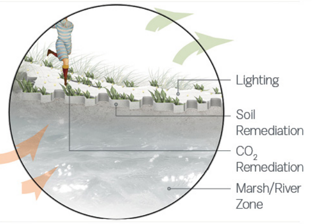
Fishtown Recreation Center	
Exposure to Pollution	63rd
Pollution Burden	76th
Child Lead Risk	48th
Sensitive Populations *(population with asthma/cancer/disability)*	4th
Poverty	35th

Penn Treaty Park	
Exposure to Pollution	96th
Pollution Burden	97th
Child Lead Risk	15th
Sensitive Populations *(population with asthma/cancer/disability)*	1st
Poverty	9th

I-95 Highway	
Exposure to Pollution	63rd
Pollution Burden	76th
Child Lead Risk	48th
Sensitive Populations *(population with asthma/cancer/disability)*	4th
Poverty	35th

(b) Marsh Soil Health Remediation at Penn Treaty River Park

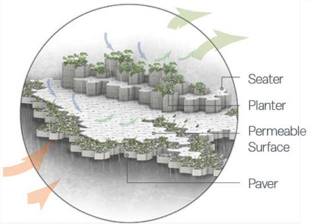
\+ O_2
\+ Soil Remediation
\+ Trail



- CO_2
- Soil Pollution
- Marsh

(c) Revitalization and Multi-Remediation on Vacant Lots Adjacent to I-95 Highway

- Storm Management
- Soil Remediation
- Air Remediation
- Gathering



- Urban Run-off
- CO_2
- Soil Pollution
- Empty Lot

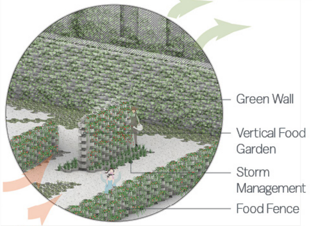
(d) Vegetation and Multi-Remediation in Street Hardscapes

- Sound Barrier
- Heat Remediation
- Soil Remediation
- Air Remediation
- Food Source

- Noise
- CO_2
- Soil Pollution
- Bare Bricks

(e) Edible Food Gardens and Stormwater Management on Recreation Center Grounds

- Sound Barrier
- Heat Remediation
- Soil Remediation
- Air Remediation
- Food Source



- Noise
- CO_2
- Soil Pollution
- Urban Heat
- Empty Lot

Stage 1: Soil Remediation

Stage 2: Urban Agriculture

(a) Adapted from PennEnviroScreen Reports

(e) Adapted from (Zhang 2025)

As reported by Pennsylvania's Department of Environmental Protection (PADEP 2025), these areas suffer from high presence of industrial heavy metals in soil, from high heat and air pollution from carbon dioxide due to low tree canopy coverage, and from traffic exhaust and tire emissions of toxic particulate matter from surrounding I-95 highway (Figure 4a, and as shown in Figure 1). On top of needed bioremediation, areas selected for SimbioBrick II interventions are characterized by exposed hardscapes such as concrete and brick, with artificial turf in places replacing natural greenery—lacking vegetation or leisure spaces.

Hardscaped, barren areas are transformed into a green, inviting space with bioremediating pavers, edible gardens, and outdoor seating. SimbioBricks support pollution mitigation, stormwater management, and local food production, creating a more sustainable, healthy, and socially vibrant environment.

At Penn Treaty Park River Walk, a modular paving system is designed as a soil remediation strategy and organizational framework for marsh landscapes, mediating high lead and particulate matter pollution levels. This is possible since the pavers are not capped in their bottom face and allow the AMF–alfalfa symbiotic system to bind soil heavy metals to the plant roots throughout the entire existing soil as the system proliferates beyond the bricks. This prevents toxic particles from becoming airborne and damaging to human health (Figure 4b).

In vacant lots adjacent to the I-95 highway, the system transforms barren hardscapes into outdoor seating, rain gardens for stormwater management, soil and air pollution mitigation, and greening the highway edge to absorb traffic noise and propose a more vibrant community space (Figure 4c). Along the neighborhood, SimbioBrick fence and paving systems on vegetation-lacking streets, reference local brick architecture while providing protection from highway runoffs and sun exposure, mitigating carbon dioxide emissions, greening former concrete pavers while remediating soil pollution, and integrating edible fences to support household food resources (Figure 4d).

Finally at the Recreation Center, the system creates a first phase of soil decontamination by, as described earlier, binding existing soil heavy metals in an initial sacrificial harvest cycle. This later allows for food to be safely grown, becoming an outdoor food garden for the neighborhood schools and organizations, as well as air heat and pollution mitigating green gathering spaces enhancing community engagement (Figure 4e).

Outlook on Urban Ecocentrism

While SimbioBrick II improves upon SimbioBrick I in unit scale, technical material development, structural capability, and propagation connection design to ensure portability and deployment, it still is a work in progress to fulfill our passive bioremediating technology vision. SimbioBrick faces challenges in water management over long-term use, especially with the wax lining potentially degrading over time.

Additionally, while the brick can be mass-produced, the transition from lab-scale additive manufacturing to industrial production may reveal unforeseen difficulties in ensuring consistent form precision and structural integrity but can also derive advantages in moving from custom printing to streamlined molding techniques. These factors require further testing and refinement before widespread implementation, and we are discussing next steps through industrial partnerships.

New policies are needed to support and regulate emerging developments in bio-based construction (Dams et al. 2023) and in bioremediating architectural systems (Ladu and Quitzow 2017) linked to urban agriculture and hyper-local strategic greening.

In our opinion, focus is needed on standardization of testing and characterization of hybrid systems that bridge biology and construction technology such as ASTM testing standards for composites. This will enable much needed streamlined approvals of site testing vehicles for certification opening up municipal adoption. Trans-disciplinary and trans-sector collaboration will allow the field of bioremediating architecture to transition from academic invention to urban environment deployment.

Looking ahead, in a time of ecological and social crisis, initiatives that bridge life sciences and social needs are indispensable, but also policies that ensure a just and equitable transition from anthropocentrism to ecocentrism. Recent research focuses on integrating ecological rights, interspecies justice, and biocultural sustainability into governance and development frameworks. It moves beyond human-centered ethics to recognize the intrinsic value of all forms of life and ecosystems (McIntyre-Mills 2018; Kotzé and French 2018; Saha 2025).

New tools of social governance on public health will soon interface with architectural design, since architecture can translate abstract ideas into tangible designs and built forms. The field may shift from one that prioritizes human comfort and dominance over nature into one that coexists with, responds to, and regenerates natural systems.

This philosophical transition changes how materials are chosen, how spaces are conceptualized, and how buildings and cities interact with ecosystems (Ricci and Favargiotti 2023). For example, biomimetic and regenerative design draws inspiration from natural systems to create buildings that mimic ecosystem processes and minimize waste. Eco-centric urban planning integrates biodiversity corridors, green roofs, and water-sensitive infrastructure to support both human and non-human life. In heritage conservation non-anthropocentric approaches treat buildings as evolving parts of ecosystems rather than static cultural artifacts. Recent builds exemplify this needed transition generating their own energy and providing habitats for species beyond humans (Eichner and Ivanova 2020; González-Díaz and García-Navarro 2011). These practices mark a movement toward architecture that values interdependence, adaptability, and ecological resilience.

Bibliography

Bae, Ji Yoon, Dorit Aviv, and Laia Mogas-Soldevila. 2024. "SimbioBrick: Carbon Sequestering Living Bricks by Fungi–Plant Symbiosis." Design Modeling Symposium DMS: Scalable Disruptors, 372–83. https://doi.org/10.1007/978-3-031-68275-9_30.

Bearak, Mark, Dora Kelle, Adam Marcier, and Phillip Anzalone. 2008. Amphorae Ecologically Sensitive Concrete. Columbia University, GSAPP, Avery Digital Fabrication Laboratory. https://amphorae.wordpress.com.

Climate Central, CC. 2024. Urban Heat Island Reports. Mapping Data. https://www.climatecentral.org/climate-matters/urban-heat-islands-2024.

Conway, Meghan. 2020. "Mapping Social Vulnerability to Air Pollution in Philadelphia, PA." *Veritas Villanova Research* Journal Environmental Science.

Cruz, Marcos. 2022. *Poikilohydric Living Walls*. Bartlett Design Research Folios. The Bartlett School of Architecture UCL. https://issuu.com/bartlettarchucl/docs/design-research-cruz-poikilohydric-walls-04.

Dams, Barrie, Maskell ,Dan, Shea ,Andrew, Allen ,Stephen, Cascione ,Valeria, and Pete and Walker. 2023. "Upscaling Bio-Based Construction: Challenges and Opportunities." *Building Research & Information* 51 (7): 764–82. https://doi.org/10.1080/09613218.2023.2204414.

Eichner, M, and Z Ivanova. 2020. "Climate Change and Eco-Anthropocentric Approach to Architectural and Urban Planning." *IOP Conference Series: Materials Science and Engineering* 953 (1): 012055. https://doi.org/10.1088/1757-899X/953/1/012055.

Foroutan, Ehsan, Tao Hu, Fan Zhang, and Hongbo Yu. 2024. "Assessing Heat Vulnerability in Philadelphia Using Geographically Weighted Principal Component Analysis (GWPCA): A Geospatial Big Data-Driven Approach." *International Journal of Applied Earth Observation and Geoinformation* 127 (March): 103653. https://doi.org/10.1016/j.jag.2024.103653.

González-Díaz, M. J., and J. García-Navarro. 2011. "Anthropocentric and Non-Anthropocentric Values as the Basis of the New Sustainable Paradigm in Architecture." December 13, 291–300. https://doi.org/10.2495/RAV110271.

Gronlund, Carina J. 2014. "Racial and Socioeconomic Disparities in Heat-Related Health Effects and Their Mechanisms: A Review." *Current Epidemiology Reports* 1 (3): 165–73. https://doi.org/10.1007/s40471-014-0014-4.

HuMUS, Project. 2023. *HuMUS Case Studies*. EU Pilots. Healthy Municipal Soils. https://www.humus-project.eu/pilot-case-studies/.

IAAC, AAG. 2020. *CO-MIDA Vertical Garden*. https://iaac.net/projects/co-mida/.

Kampa, Marilena, and Elias Castanas. 2008. "Human Health Effects of Air Pollution." *Environmental Pollution*, Proceedings of the 4th International Workshop on Biomonitoring of Atmospheric Pollution (With Emphasis on Trace Elements), vol. 151 (2): 362–67. https://doi.org/10.1016/j.envpol.2007.06.012.

Kotzé, Louis J., and Duncan French. 2018. "The Anthropocentric Ontology of International Environmental Law and the Sustainable Development Goals: Towards an Ecocentric Rule of Law in the Anthropocene." *Global Journal of Comparative Law* 7 (1): 5–36. https://doi.org/10.1163/2211906X-00701002.

Ladu, Luana, and Rainer Quitzow. 2017. "Bio-Based Economy: Policy Framework and Foresight Thinking." In *Food Waste Reduction and Valorisation: Sustainability Assessment and Policy Analysis*, edited by Piergiuseppe Morone, Franka Papendiek, and Valentina Elena Tartiu. Springer International Publishing. https://doi.org/10.1007/978-3-319-50088-1_9.

Lokko, Mae-ling. 2025. "Soil Sisters: Emerging Intersectoral Material Designs For Soil Health." *Journal of Architectural Education* 79 (1): 122–34. https://doi.org/10.1080/10464883.2025.2463832.

Mang, Pamela, and Bill Reed. 2012. "Designing from Place: A Regenerative Framework and Methodology." *Building Research & Information* 40 (1): 23–38. https://doi.org/10.1080/09613218.2012.621341.

McIntyre-Mills, Janet Judy. 2018. "Policy Design for Non-Anthropocentric Pathways to Protect Biodiversity and Re-Generate the Land." *International Journal of Educational Development in Africa* 4 (October). https://doi.org/10.25159/2312-3540/2865.

Mendez, Yessica G, and A Karen Garza Chapa. 2021. *Embedding Passive Biofiltration Systems Into Architectural Ceramic Elements*.

O'Shea, Michael, Mark Krekeler, David Vann, and Reto Gieré. 2021. "Investigation of Pb-Contaminated Soil and Road Dust in a Polluted Area of Philadelphia." *Environmental Monitoring and Assessment* 193 (July). https://doi.org/10.1007/s10661-021-09213-9.

PADEP, USA. 2025. *PennEnviroScreen*. GIS Data. Office of Environmental Justice. The Pennsylvania Department of Environmental Protection. https://gis.dep.pa.gov/PennEnviroScreen/.

Paré, Louis, Claudia Banchini, Chantal Hamel, Louis Bernier, and Franck Stefani. 2022. "A Simple and Low-Cost Technique to Initiate Single-Spore Cultures of Arbuscular Mycorrhizal Fungi Using a Superabsorbent Polymer." *Symbiosis* 88 (1): 61–73. https://doi.org/10.1007/s13199-022-00878-5.

Purcell, Dylan, Barbara Laker, and Wendy Ruderman. 2017. “In Booming Philadelphia Neighborhoods, Lead-Poisoned Soil Is Resurfacing.” News, News, News. *Philadelphia Inquirer*. *https://www.inquirer.com/news/inq/philadelphia-lead-soil-fishtown-construction-dust-20170618.html*.

Ricci, Merce, and Sara Favargiotti. 2023. *Leaf Plan: Towards the Ecological Transition*. 1st ed. ACTAR Publishers. *https://actar.com/product/leaf-plan/*.

Saha, Shantanu. 2025. “A Call for Transitioning to an Ecocentric Approach to Further the Sustainability Paradigm Focusing on Nature–Human Relationship.” *Jindal Global Law Review* 16 (1): 335–56. *https://doi.org/10.1007/s41020-025-00270-6*.

Sandak, Anna, Jakub Sandak, Marcin Brzezicki, and Andreja. 2019. Bio-Based Building Skin. 1st ed. Environmental Footprints and Eco-Design of Products and Processes. Springer Professional. *https://www.springerprofessional.de/bio-based-building-skin/16887126*.

Shafique, Muhammad, Xiaolong Xue, and Xiaowei Luo. 2020. “An Overview of Carbon Sequestration of Green Roofs in Urban Areas.” *Urban Forestry & Urban Greening* 47 (January): 126515. *https://doi.org/10.1016/j.ufug.2019.126515*.

Sommese, Francesco, Lorenzo Diana, Simona Colajanni, Marco Bellomo, Gaetano Sciuto, and Grazia Lombardo. 2025. “Towards a Regenerative and Climate-Resilient Built Environment: Greening Lessons from European Cities.” *Buildings* 15 (11): 11. *https://doi.org/10.3390/buildings15111878*.

UrbiNat, NBS. 2022. “Ceramic Green Wall.” *https://urbinat.ces.uc.pt/nbs/ceramic-green-wall/*.

Zhang, Boyi (Zoyce). 2025. “Living Structure from Living Materials.” MArch Thesis, University of Pennsylvania, Stuart Weitzman School of Design, Department of Graduate Architecture, DumoLab Research (DLR).

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