CanoPIT: Valorizing Unavoidable Fruit Waste into Printable Biomaterial Surfaces for Participatory Learning

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ABSTRACT

CanoPIT proposes a canopy structure composed of fruit-based biomaterials that transforms unavoidable food waste from stone fruits into bio-based printable blends outputting strong, healthy, biodegradable, and functional large-scale surfaces. The interdisciplinary approach combines biomaterial blend development and hierarchical additive fabrication technology to develop a multi-layered bio-surface with multiple benefits, acting as (1) seasonal weather protection for community events, (2) educational beacons for a waste-free sustainable materials future, and (3) testing platforms collecting data to channel future design for decay.

INTRODUCTION: FOOD WASTE AS BUILDING MATERIALS

In the city of Philadelphia, 17% of trash is food waste (City of Philadelphia 2020), and without composting, it ends up in landfills or incinerators, generating pollutants that deteriorate the environment as well as human and wildlife health (Giusti 2009). Pits or stones in fruits like avocado, peach, and mango generate non-edible, unavoidable waste but have the potential to be transformed into functional products. Avocado pit waste has been used to produce food supplements (Gómez et al. 2014), bioplastic utensils (BioFase 2023), and moldable pastes (Brière 2020), and their anthocyanins have been extracted to make natural dyes (Kusumastuti et al. 2023). Avocado pits make up 20% of the avocado mass and are composed of carbohydrates and lignin (García-Vargas et al. 2020), presenting the potential to be explored as structural aggregates or functional fillers in bio-based building materials. Despite their mechanical properties (Roy Chong et al. 2022) of strength and biodegradability, fruit pits are not well-explored as a building material. CanoPIT proposes a methodology to reverse-engineer unavoidable food waste from locally-sourced stone fruits into optimized, bio-based, printable blends to produce surfaces with applications in the built environment (Figure 1, Figure 2).

METHODOLOGY: MULTI-LAYERED BIOMATERIAL SURFACES

We devise a multi-material, functionally-graded system using additive manufacturing in two layers defined as a base and reinforcement. Blends are composed of dehydrated avocado pits, which are washed and ground by hand, combined with natural thickeners, plasticizers, and binders derived from fishing, forestry, and agricultural by-products (Mogas-Soldevila et al. 2021) (Figure 2). We use chitosan as a binder extracted from shrimp shell waste, glycerol as a plasticizer derived from vegetable oil production, lignin sourced from yard trimmings and logging, and ground avocado pits waste as fillers (Figure 3). Chitosan (85% deacetylation), and glycerol were sourced from Sigma Aldrich; lignin was sourced from Eastchem, and avocado waste was sourced from local establishments. The labor process of the avocado pits does not compromise material innovation since such processes can easily be completed at manufacturing scale.

INITIAL DEVELOPMENT

Sodium alginate is a biopolymer extracted from brown algae (Qiang Ao 2021). It was at first used as binder in both the base material and reinforcement blends. However, due to the rapid degradation and extreme hydrophilicity observed, chitosan was substituted to confer durability fit for our envisioned applications. Unlike sodium alginate (Frent et al. 2022), chitosan exhibits low solubility in water due to its strong intermolecular and intramolecular hydrogen bonding and antimicrobial properties (Li et al. 2019, Rabea et al. 2003), which make for a more suitable ingredient for creating water-resistant materials.

MECHANICAL PERFORMANCE

The developed material system is composed of two layers of biomaterials. An initial flexible base layer contains finely ground avocado pit (19% at 0.3mm granular size) plasticized with glycerol (19%) and bound by chitosan biopolymer (62% at 8% w/v concentration in 4.5% acetic acid). Figure 5 shows the average

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Figure 1. CanoPIT prototype using multi-layered biomaterial surfaces.

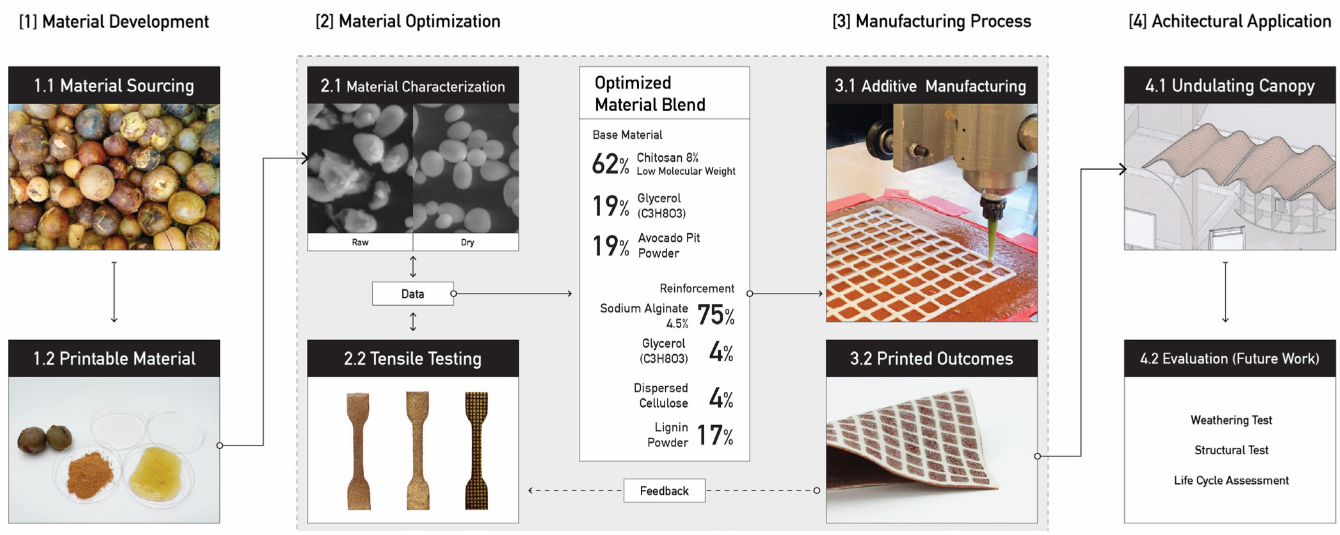

Figure 2. Research framework developing multi-layered biomaterial surface.

tensile strength of four different blends of avocado base material. Blend 3 (62% chitosan at 8% w/v concentration in 4.5% acetic acid, 19% glycerol, and 19% avocado powder) was chosen as the final base layer formula due to its promising tensile strength results. On top, a printed, off-white-colored layer confers improved tensile strength to the system via geometry produced with computationally programmed toolpaths along stress lines and chemistry using composites of cellulose pulp (4%) and lignin powder (17%) bound by sodium alginate 4.5% (75%) and plasticized with glycerol (4%) (Figure 3, Figure 4). The structural capacity of the multi-layered biomaterial surface has an average tensile strength at break at 0.56 MPa, comparable to the tensile strength of mycelium films (0.6-1.2 MPa (Haneef et al. 2017)). However, it is still weaker than pineapple leather (2.5-3.3 MPa (Pinatex 2018)). In order to further improve strength and water resistance of the bilayer, we have begun iterating formulation, and further testing is needed.

In sum, our method achieves a chemically bound, multi-layered biomaterial surface with tunable shape, aroma, flexibility, strength, and degradation, promoting a healthier built environment by leveraging water-based surface additive manufacturing (Figure 6).

DEVELOPMENT: A SEASONAL CANOPY STRUCTURE

The CanoPIT project develops a scaled-down prototype using multi-layered avocado pit and lignin biomaterial surfaces and minimal supports to create an undulating canopy sustaining self-load. Structural simulation informs lignin toolpaths as a reinforcement strategy while minimizing material usage. In convex (upward) undulation, the middle of the surface receives more pressure than each edge, which informs the lignin toolpath pattern to be denser in the middle and minimized at points where it receives the lowest pressure. Conversely, edges receive increased pressure at concave (downward) undulation due to the effects of drape (Figure 7). An easily-deployed, minimal support structure is designed to hold the biomaterial surface efficiently and help maintain its intended triple undulation curvature. This structure is designed to be reused until the seasonal end of life of the canopy (Figure 8).

CONCLUSION: SUMMARY AND FUTURE WORK

We designed an undulating canopy structure using biomaterial waste of stone fruits with a shape informed by geometric analysis and distributed material properties. In order to validate the system's feasibility, we developed a scaled-down canopy prototype leveraging surface-printing technology. A flexible base layer is frame-casted from avocado pit blends. A lignin top layer braces the system and contributes to its convex-concave shaping with structural simulation-informed toolpathing. The system delivers novel aesthetics that promote dialogue about organic waste valorization and digital biofabrication. The undulating canopy stands aided by a supporting structure performing as a building composite.

In the next phase, we plan to improve weathering and install a 1:1 scale canopy as an educational beacon for the community in South Philadelphia during seasonal markets with undulating shapes based on the varied behavior of our fruit waste blends studied in this article. However, the final toolpathing design will be based on the actual scale of the canopy (Figure 9), which will 1) shade a reunion space for targeted learning about existing food waste issues in the city, 2) host outreach workshops on food waste-based material making, and 3) and demonstrate biomaterials' potential to become building systems for healthier futures.

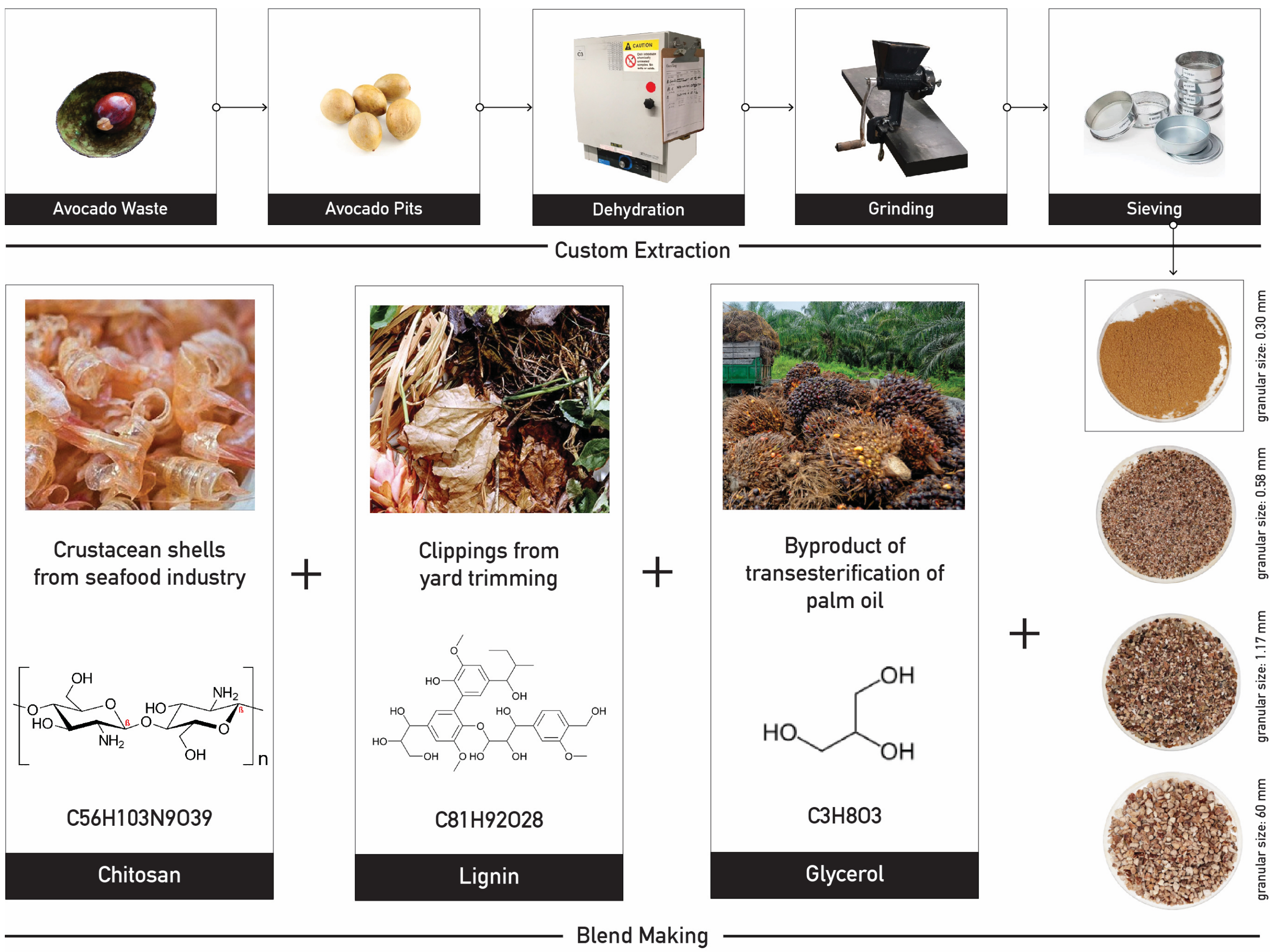

Figure 3. Material processing and ingredients sourced from nature.

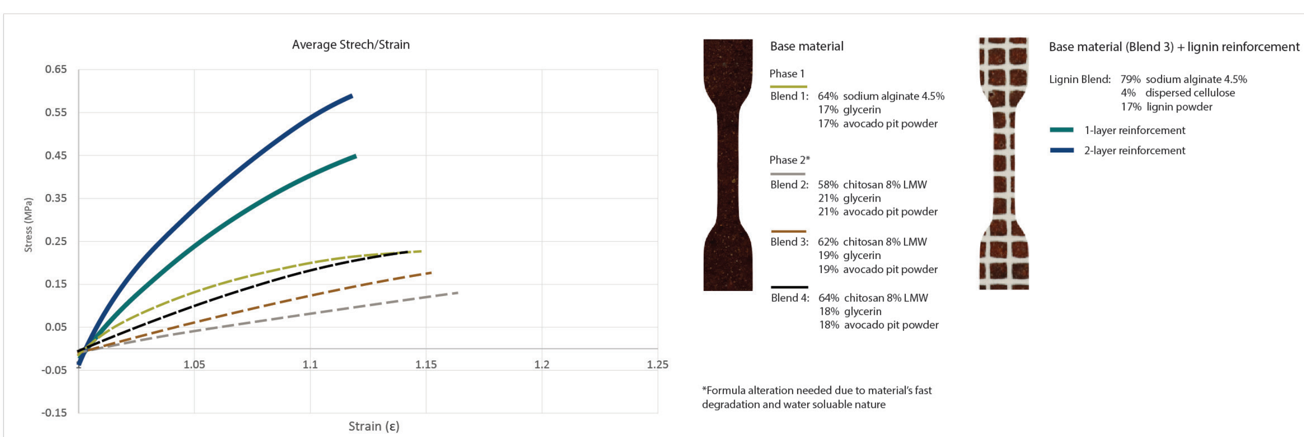

Figure 5. Tensile strength testing with parameters measured in stress and strain of base layer and reinforcement layer.

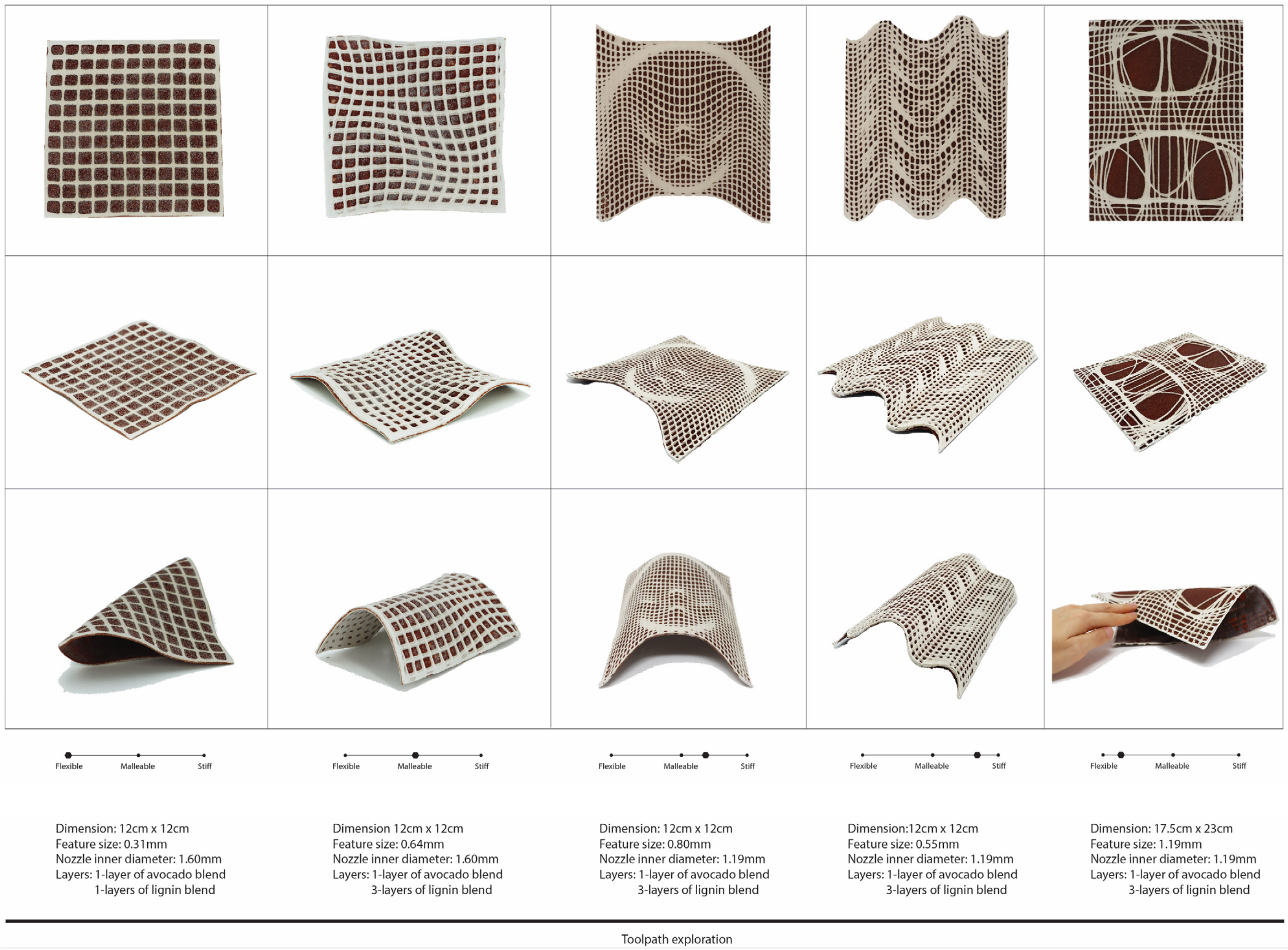

Figure 4. Exploration of different toolpath patterns and layers as structural reinforcement

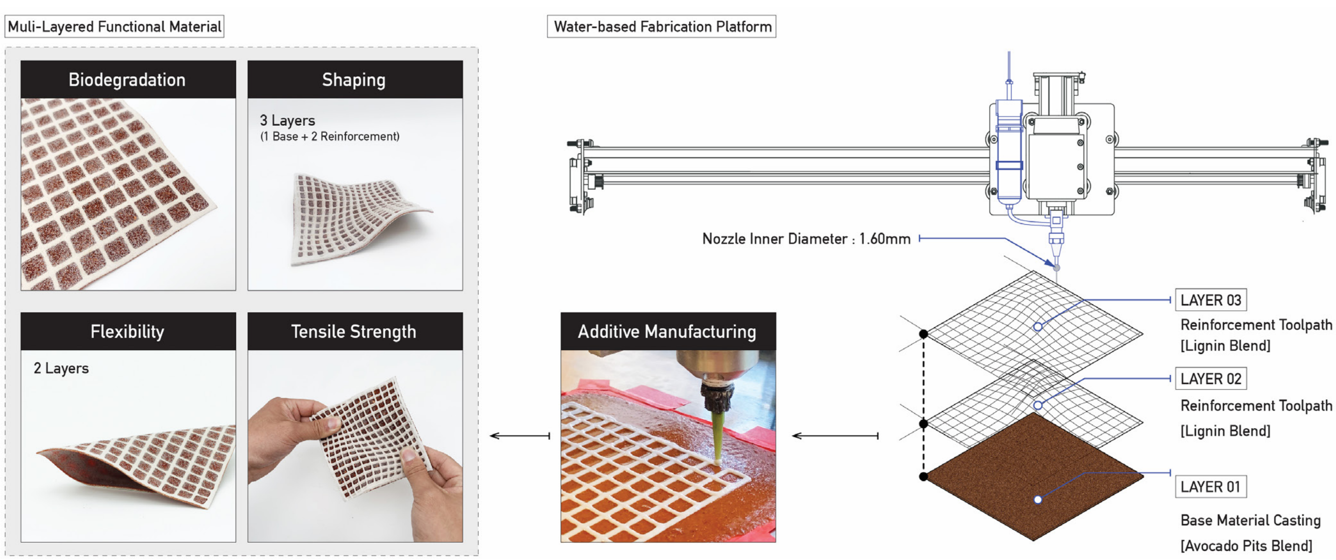

Figure 6. Muli-layered biomaterial surface system.

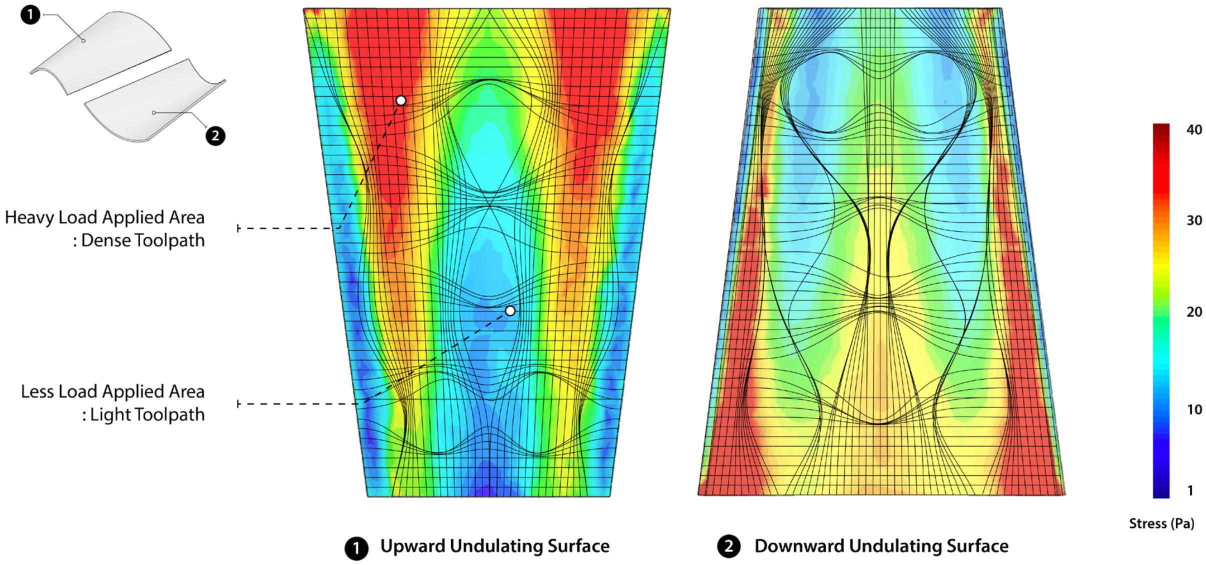

Figure 7. Structural simulation informing toolpath design.

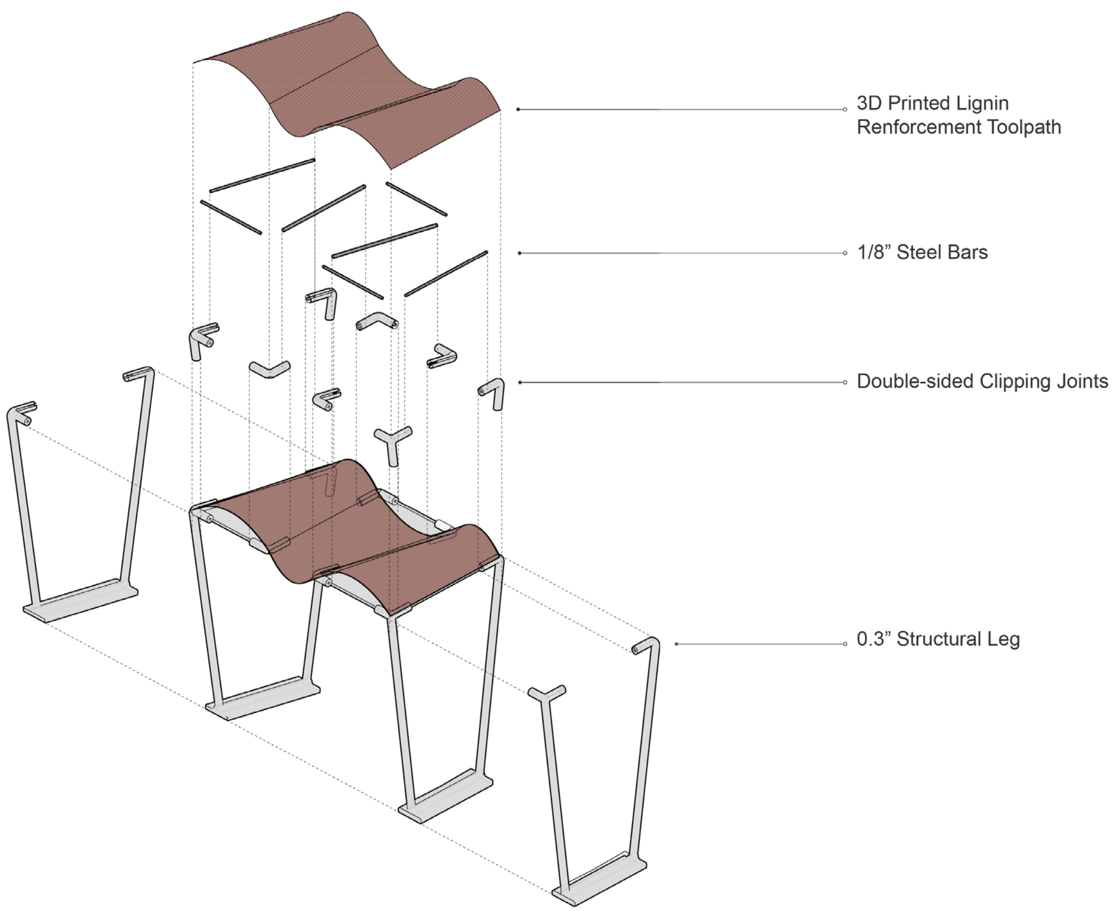

Figure 8. Structural design detail to support canopy.

PROJECT

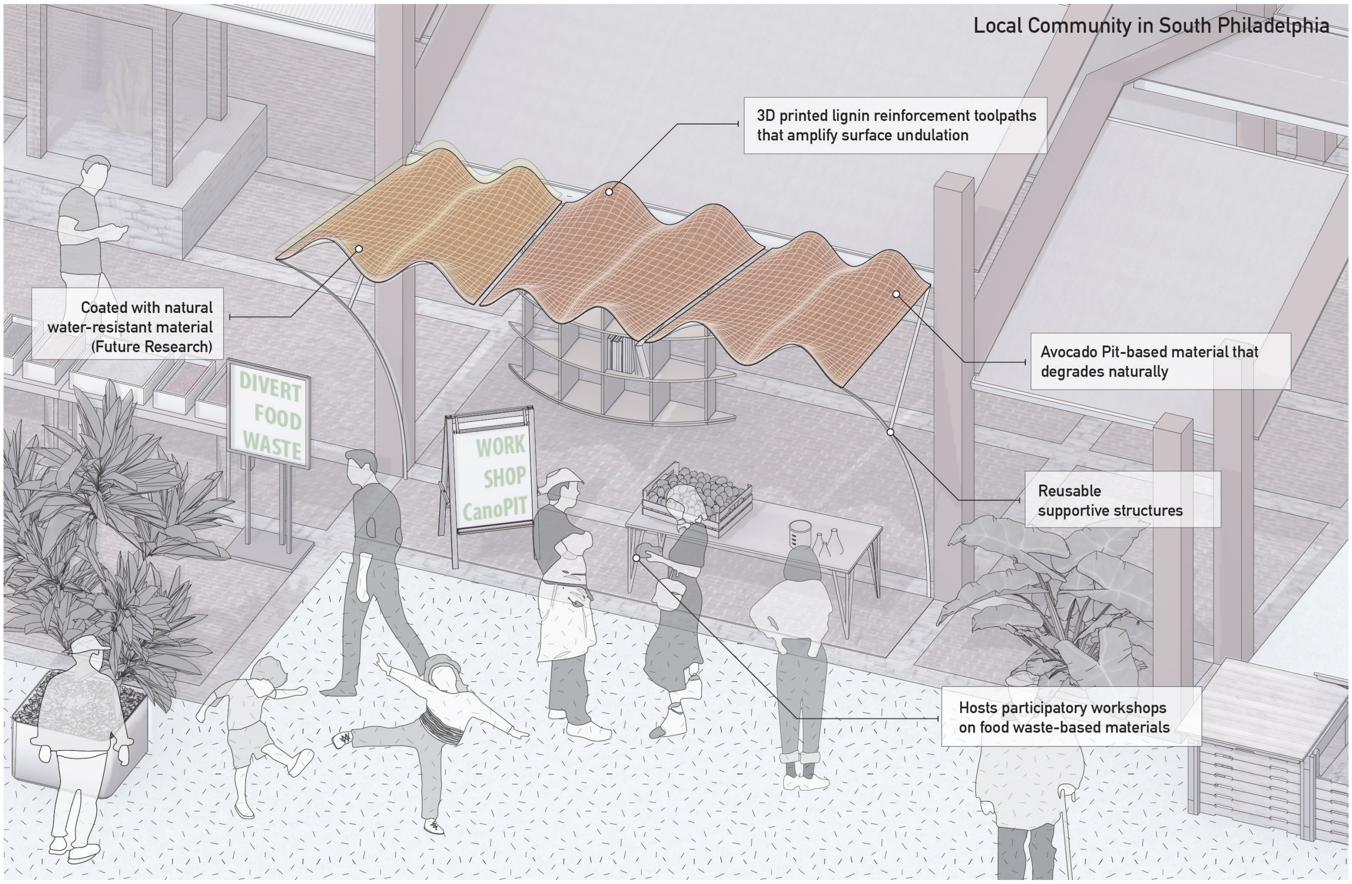

Figure 9. Seasonal large-scale canopy structure in a community market.

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