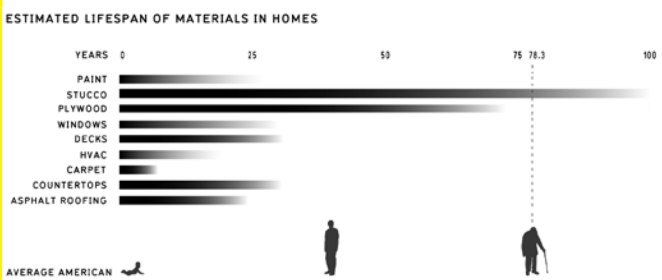
MEGA-MICROBESTRUCTURES

Marisha Farnsworth

Architects and designers must harness the very processes of decay, cannibalizing our existing buildings to construct new architectural forms.

Microorganisms already construct our environment: the air we breathe, the soil we walk on; even our own bodies are 99% microorganism by DNA. Employing microorganisms, the great decomposers, we can harness existing systems of decay to produce new structures that exist in a cycle of growth and decay. The new microbetecture will evolve with our changing needs. Architects will design not only construction, but demolition, an often overlooked architectural process, as well.

Our current construction methods comprise between 25-30% of the waste in our landfills. Conventional buildings are fugitive, in constant combat with the forces of decay. Degraded by sun, wind, water and wear and tear our conventional buildings require regular maintenance. The finishes in these buildings slough off and are replaced regularly, much like the skin on our own bodies.



Not only decay, but remodeling, changing land values, and changing programmatic needs contribute to the short live-span of conventional building. In a study from 2004 on the actual service lives of North American buildings, researchers found that even buildings we consider permanent: buildings made of steel, concrete and wood last only as long as the humans who inhabit them**. In our rapidly changing society, we must seek architectural systems that can keep pace with our growth and desires.

*Data from "Study of Life Expectancy of Home Components" National Association of Home Builders, 2007.

**O'Conner, Jennifer, et al. "Survey on actual service lives for North American Buildings." 2004

Previous page and above: Living Fungus Model with 3d printed bacterial-plastic interior and exterior humidity enclosure (fungus not to scale). Interior-section view.

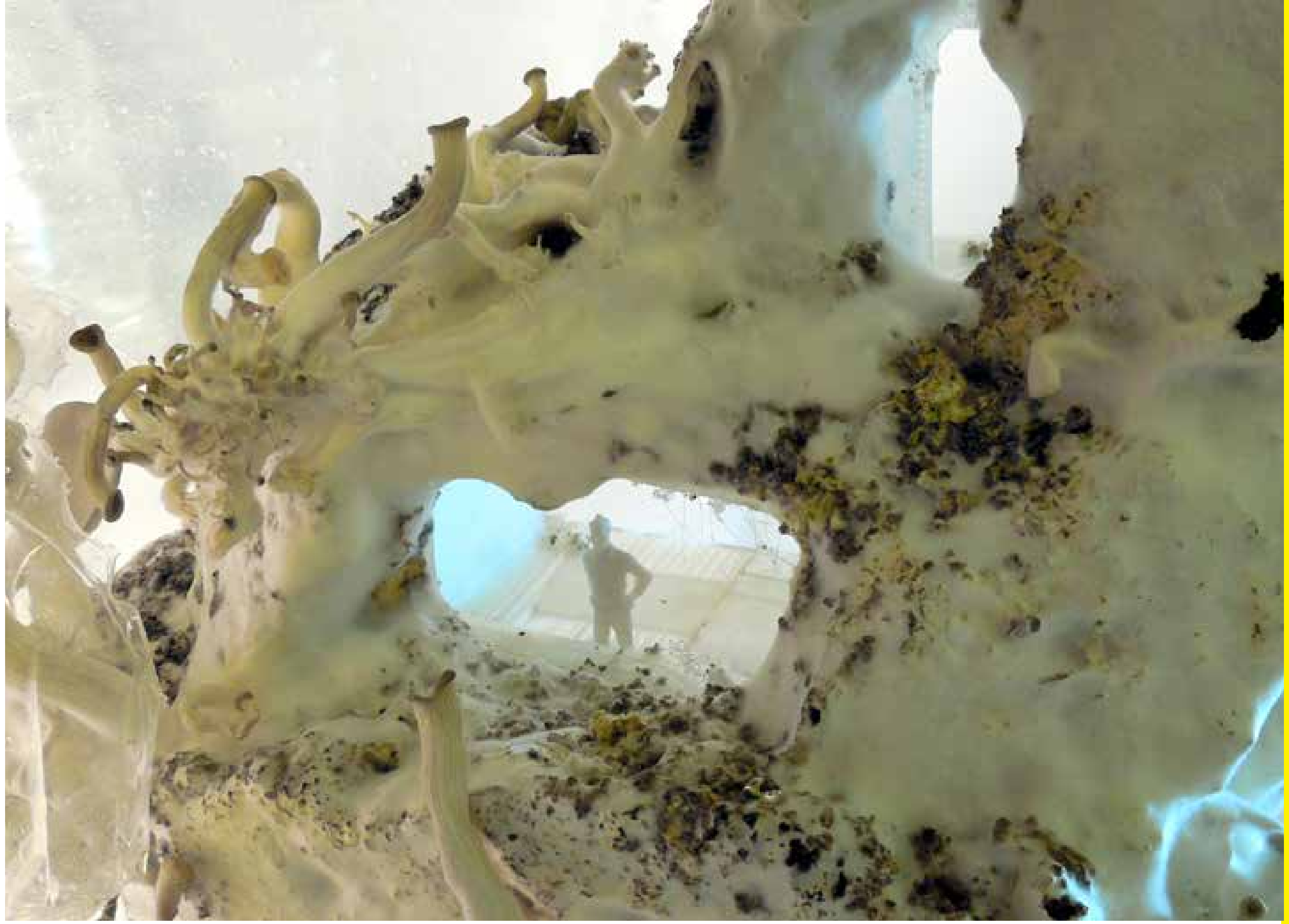
Conventional construction processes engender waste, inefficiency and pollution. Harnessing microbes and their processes of decay we can create the spaces that we desire, transforming our waste into new forms and remediating the urban landscape.

Microorganisms can produce materials similar to those currently used in construction: insulation, plastic and stone-like substances. These materials are generated as microbes consume waste: construction waste, refuse, sewage sludge, agricultural waste, and desalination effluent can be transformed into new materials.

Microbe-construction is a process of improving our building culture through cultivation and fermentation: arranging nutrients and enacting specific environmental conditions to orchestrate growth and decomposition.

Where our waste is collected municipally or consolidated through industrial processes, microbe materials can be grown in a large-scale operations as add-ons to our previously wasteful systems. Living with microbe-structures, cultivation can be more individual. Inhabitants assume the role of the designer-cultivator. Maintenance no longer entails a trip to the Home Depot, but involves a continual process of cultivation in fungal gardens, fermentation vats and nutrient preparations where residents develop the materials that best suit their needs. Strains can be identified and selected for their performance, for example: rate of growth, resistance to infection, color, durability, or insulation value. Neighborhoods are defined by microbial strains.

While some microorganisms can produce desirable building materials, others create conditions dangerous for humans. Microorganisms already exist all around us, in us and on us, in a constant struggle for dominance; the cultivators of microorganism structures must work to maintain a healthy culture. As new atmospheres and environments challenge the way that we cohabitate with other life forms and designers learn to manipulate these cyclical building systems, a new non-linear architecture emerges.



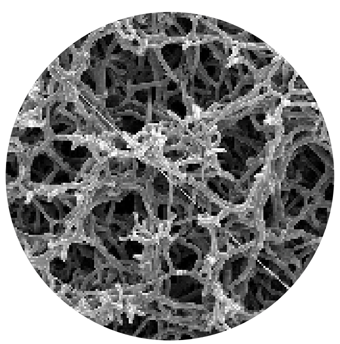
Opposite above: Living Fungus Model, exterior view.
Opposite below: Desiccated Fungus model, interior view.

THE MANUAL

Building with Microbes is a manual that outlines construction methods for cultivating microbes as a material for construction. The building systems included are varied, both in the organisms that they employ and in the way those organisms are organized: as living matter, dead matter and even edible matter. The methods included range from the very practical to the speculative.

BUILDING WITH MICROBES

A Handbook of Construction Methods



MATS

PRINCIPLES OF CONSTRUCTION:

Mat structures can be grown from various organisms, but one of the most widely used is the mycorrhizal fungal mat. Mats are lightweight and grow in a continuous structure composed of small branching threads; because of these qualities, mats are appropriate for building insulation as well as structural composite systems. Mats can be grown in a production facility or in situ. Nutrient for mats are primarily agricultural waste and waste housing stock, such as chipped wood products.

REMEDIATIVE BENEFITS

Discarded wood from remodelling or demolition may be chipped and consumed by the mat wall. Reusing components of existing buildings has as a nutrient source has the added benefit of encapsulating dangerous building materials, such as lead paint, thereby diverting them from landfill. The growth of the mycorrhizal fungal mat not only isolates the contaminant, but is inherently a bio-geochemical remediative process which can, for example, breakdown hydrocarbons or chemically transform lead paint into pyromorphite, which is harmless for humans. CAUTION: Chipping of contaminated wood is potentially hazardous and should only occur at a certified facility or a certified Mobile Mat Truck.

FORMWORK

One of the principle benefits of mat construction is the characteristic of the mat to grow continuously in any formwork where nutrients are placed. Mat structures are therefor formally diverse. Formwork for in-situ construction range from leave-in-place rigid bioplastic, to reusable inflatable form work, to stacked straw bales, which have been used for farm worker housing.

CONSIDERATIONS

Mycorrhizal mats require specific growing conditions including humidity, shade and access to oxygen. Unless specific oxygenation measures are taken, mats should be grown in skins no thicker than 6." To achieve thicker walls, subsequent skins can be grown in layers as new growth will readily adhere to the dead material from the previous skin.

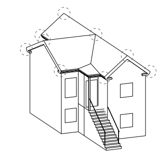
GROWTH

Care should be taken to cure mat structures at the appropriate moment. Optimum growth will appear as a solid white surface, at which point rapid desiccation is necessary to halt further growth. If left too long, primordia and fruiting bodies will emerge on the surface of the wall, generating spoor, which could cause fungal growth in undesirable areas.

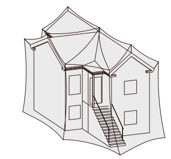
Living walls and fungus gardens cultivated for culinary and aesthetic reasons may serve as a reserve building stock. Successful fungal strains may be selected and multiplied on shade covered building surfaces.

TARPS AND SHADE

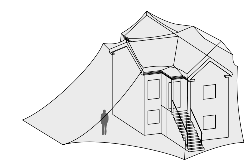
Mycorrhizal mats are accustomed to growing underground and must therefor be protected from sun and wind when grown for construction. Semipermeable shade cloths are essential for the in-situ growing period (2-4 weeks). After this period, cloths may be removed altogether, or retained either for the formation of fungal gardens or in anticipation of future remodels.



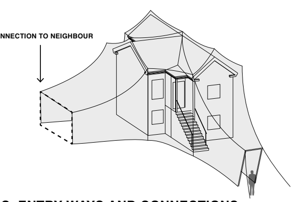
1. IDENTIFY KEY POINTS



2A. BASIC SHADE STRUCTURE



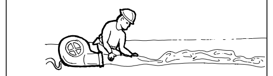
2B. FUNGAL GARDEN OPTION



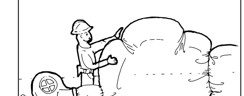
2C. ENTRY WAYS AND CONNECTIONS

INFLATABLE FORMWORK

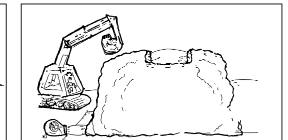
Because mat materials are lightweight, inflatable forms may be employed. Inflatable forms are reusable, although the desire for customization necessitates frequent fabrication of unique formwork.



1. LAY FORM ON FOUNDATION
Design foundation to with sufficient area for 6" variation in wall thickness.



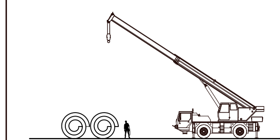
2. INFLATE FORM



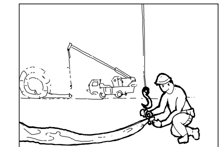
3. INSTALL NUTRIENTS
Pack inoculated nutrients over form and cover with shade cloth.

CATENARY FORMWORK FOR VAULTED STRUCTURES

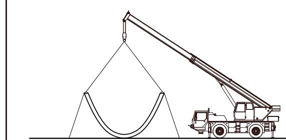
Catenary formwork makes use of gravity to organize mats into vaults.



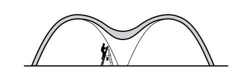
1. UNROLL MYCELIUM SHEETS
Mycelium sheets consist of inoculated nutrients in two layers of quilted plastic composite. Sheets should be used within 24 hours of delivery.



Connect pick points of mycelium sheet to crane arm.



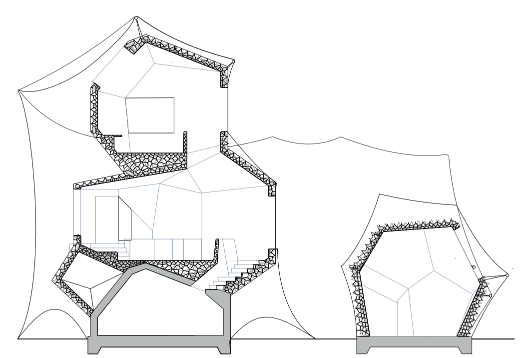
2. SUSPEND AND ANCHOR
Suspend sheets and anchor to the ground to achieve desired arch.



3. INVERT AND CONNECT
Desiccate arches and invert. Grow arches together with new mat material.

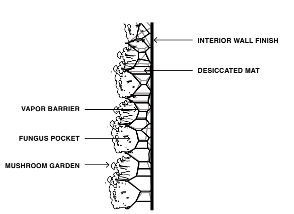
COMPOSITE POD STRUCTURE

Bioplastic leave-in-place form work creates a dry and impermeable inner surface for human occupation and a toothy substrate for mat growth on the exterior. The mycelium mat is grown through the extruded bioplastic web. Together the interlocking web and mat create a robust structure.

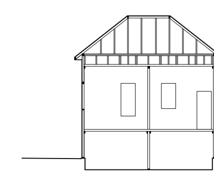


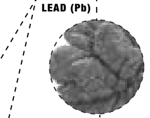
The outer surface of the pod contains pockets where mycelium may be cultivated as a living wall. A vapor barrier must be installed between desiccated and living mat layers to prevent the total consumption of the structure by the living wall.

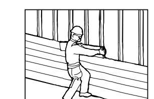
If an expansion or addition to the building is desired, a new pod may be grown on to the existing living wall and desiccated.



MYCO-RECOMPOSITION OF A LEAD CONTAMINATED HOUSE



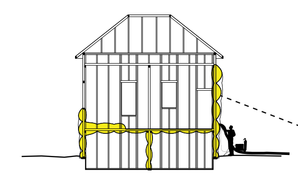


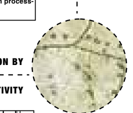


Carefully remove siding and interior finishes containing lead paint.

1. IDENTIFY CONTAMINATES
Current building stock contains a host of materials hazardous to health. These can include but are not limited to: lead, asbestos, formaldehyde, and vinyl chloride

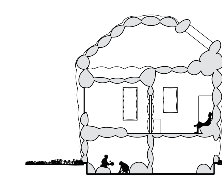
Components are chipped, and sterilized in the mycelium processing facility.

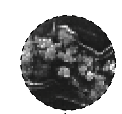




2. DIGEST COMPONENTS
Unwanted materials are removed, ground, sterilized, inoculated and blown back into flexible form work attached to the original structure.

Attach bioplastic to the original studs.



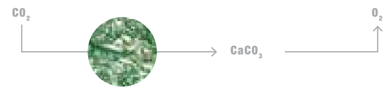


3. DESICCATE FORMS
After full fungal colonization, the hyphae are heated and desiccated freezing new forms as structure and insulation.

FILMS

PRINCIPLES OF CONSTRUCTION

Films are abundant and grow in a variety of conditions. Films grow rapidly and have the benefit of being self-healing. As they require a constant source of moisture, construction applications should be constrained to exterior surfaces in areas where moisture is readily available, such as structures near mineral springs, oceans and other waterfront territories. While there are many films that may, with further research, be applicable for structures, calcium precipitating bacteria are one of the most promising as they produce a stone-like substance. Stromatolites, are an example of this biological geo-forming; a substance made by a community of bacteria dominated by cyanobacteria. The growth of this material has the added benefit of sequestering CO_2. If every costal city in the US was covered in this film, our atmosphere would be radically changed.

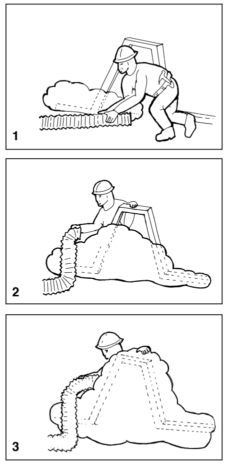


BACTERIALLY INDUCED CALCIUM CARBONATE WALL

Calcium carbonate walls will form only with a constant deposition of water containing calcium, such as sea water, so sites should be selected based on proximity to an appropriate water source.

Water delivery equipment should be sized appropriately to reduce calcification. Locate water delivery at the upper most point of the site. Site work including retaining walls and or drainage trenches may be required. Existing structures may be used as a base frame, in some cases the construction of new frameworks may be necessary.

Regular maintenance is required to rearrange water delivery systems as the structure grows.



SUSPENSION

PRINCIPLES OF CONSTRUCTION

Suspensions consist of particles of any material that are dispersed but not dissolved in a fluid. Microbial material is grown in a nutrient fluid, generally a readily available waste stream such as a sewage treatment plant, and then formed by heat into a fused plastic building material of any form.

GROWTH

Suspensions are a common form of cultivating microorganisms. All microorganisms and multicellular organisms are inherently either adherent or suspended: skin cells are adherent, while blood cells are suspended. In microbiological construction, suspensions are used to provide ideal nutrients that allow for maximum efficiency in growth. Many organisms that occur in water bodies are growing in suspension, for example the PHA producing bacteria which have been investigated here, historically grew in nutrient rich waters.

PROCESSING

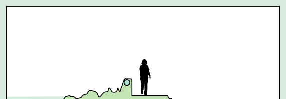
After cultivation the bacteria, can then be dried or drained, filtered from the growth media, centrifuged and finally thermoformed. The thermoforming converts the otherwise fugitive organism into a semi-permanent building material, which under the right conditions remains biodegradable. The filtration and centrifuge process can be omitted to develop a building material with more irregular character and coloration, representational of the original nutrient source. Other waste stream products such as wood dust and bast fibers may be mixed into the PHA to create composite materials of varied strengths.

CONSIDERATIONS

While this process requires multiple steps to develop a final building product, including energy consuming heat extrusion or thermoforming, it provides incredible flexibility in fabrication, shape, form and thickness of the final product which can be worked and moulded like petroleum based plastics.

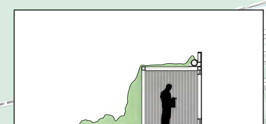
STROMATOLITE WALL NEAR DESALINATION PLANT

Stromatolites, the microbially manufactured geologies that one dominated our shorelines and fabricated an atmosphere fit for humans and other species, can now produce an architectural-atmospheric system. Sea change in combination with a desalination plant create ideal conditions for a bacterial films. In coastal areas around the world, bacterial walls define a new architecture.



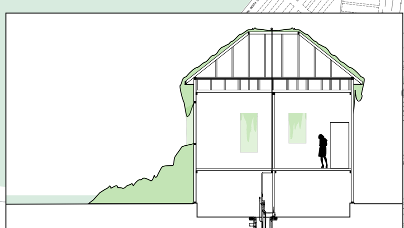
CONTINUOUS SHORELINE PATH

Bacterial living walkways grow with the rising sea level, providing circulation paths through newly formed brackish marshes that cover former fill.



PORT OFFICES

Discarded shipping containers provide the base structure for bacterial sea walls as rising tides threaten the low-lying port.



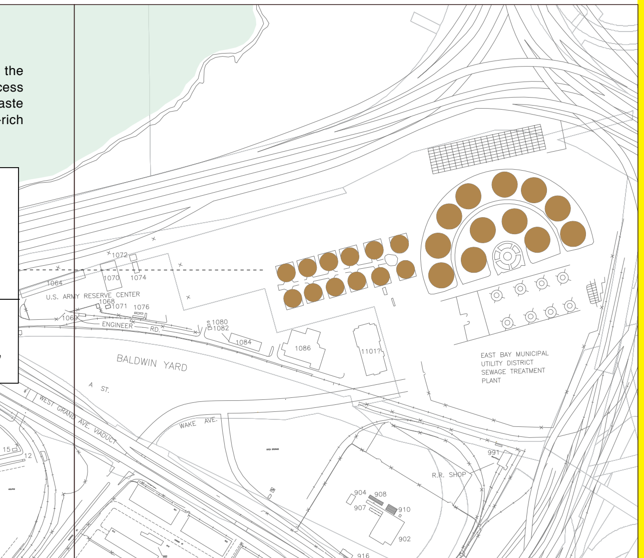
WATER FRONT RESIDENCE

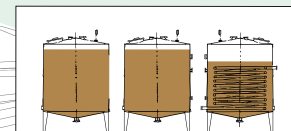
The inevitable necessity of sump-pumps comprises the new mechanical infrastructure that will at once keep residences dry on the interior while creating an evolving bacterial landscape and fortification on the exterior.

OAKLAND, CA

BIOPLASTIC FORMS AND COMPONENTS

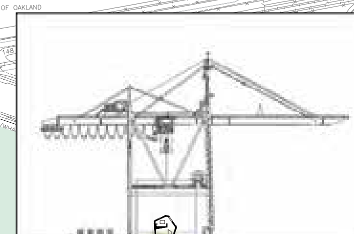
PHA is a bioplastic that can be produced from human waste alone, without the costly inputs associated with other bioplastics. The fermentation process requires the addition of equipment and tanks to be installed at the existing waste treatment facility, but otherwise takes advantage of an underutilized nutrient-rich waste product.





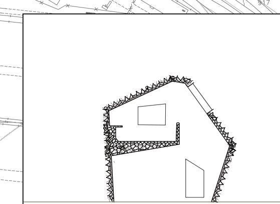
1. FERMENT NUTRIENTS

Sewage sludge is collected and fermented in new fermentation tanks at the wastewater treatment plant.



2. EXTRUDE BACTERIA

Bacteria are heat extruded, fusing their stored PHA into a solid form. Former shipping cranes are adapted as the armature for heat extrusion machines large enough to produce a room sized pod.



3. ASSEMBLE PODS

Extruded pods can be assembled into buildings and should be combined with other materials such as mat insulation.

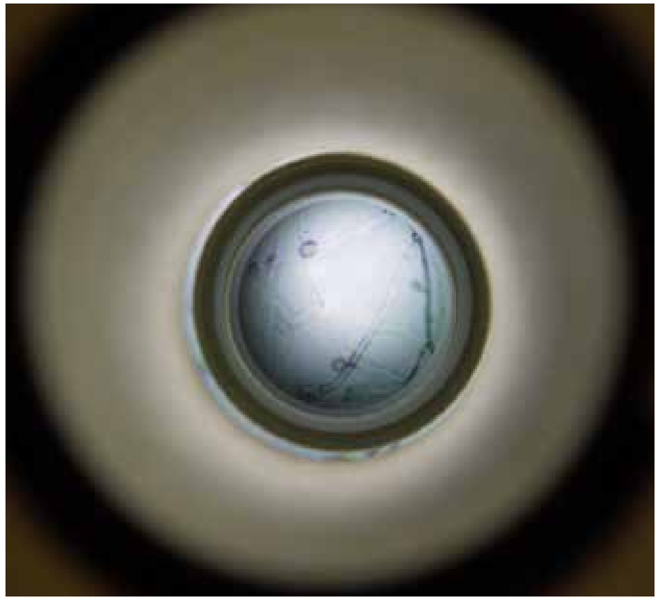
A MICROBIAL CASE STUDY

To understand experiential possibilities of microbe structures, this case study explores a site over a period of time as an existing neighborhood is transformed into a microbial future.

The prototypical site, located in Oakland, California is adjacent to multiple nutrient streams: the sewage treatment plant where bacterial-plastic is produced and a planned desalination plant where sea water effluent is turned into stone infrastructure. The neighborhood has an older building stock dating to the Victorian era. Rotting is common and the earth and homes are contaminated with old flaking lead paint and lead residue from the adjacent freeway.

As desire for new living spaces transform the Victorian houses of the neighborhood, walls are decayed, rooms reconfigured and new mycelial walls consume the existing wood walls. As the lead paint covered wood surfaces are consumed, the lead is transformed into pyromorphite, a substance harmless for humans. The new thickened walls create an insulative barrier to the freeway traffic .

Experiments in bacterial-plastic forms evolve into a packing system, where rooms can be added onto the existing structure at will. Bacterial-plastic is heat extruded into a mat structure for mycelium to grow through. Inner walls of the apartments are smooth

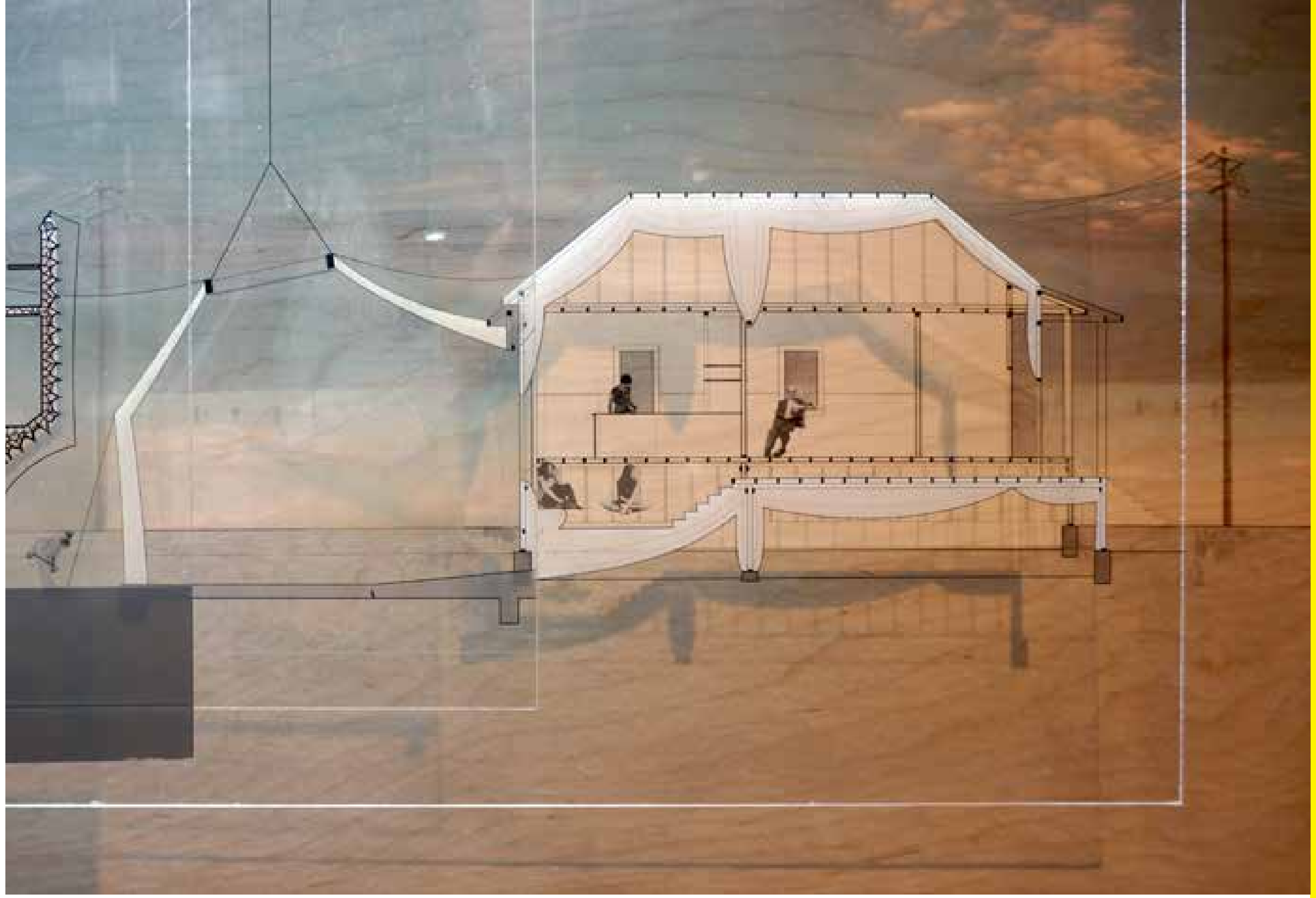


Previous page: Thesis show installation in Wurster Hall, UC Berkeley, 2012. **Opposite:** Detail: microscopic view of mycelium through drawing panel. **Above:** Material studies. **Right:** Mycelium consuming a wood framed wall, 1:1 desiccated wall section.

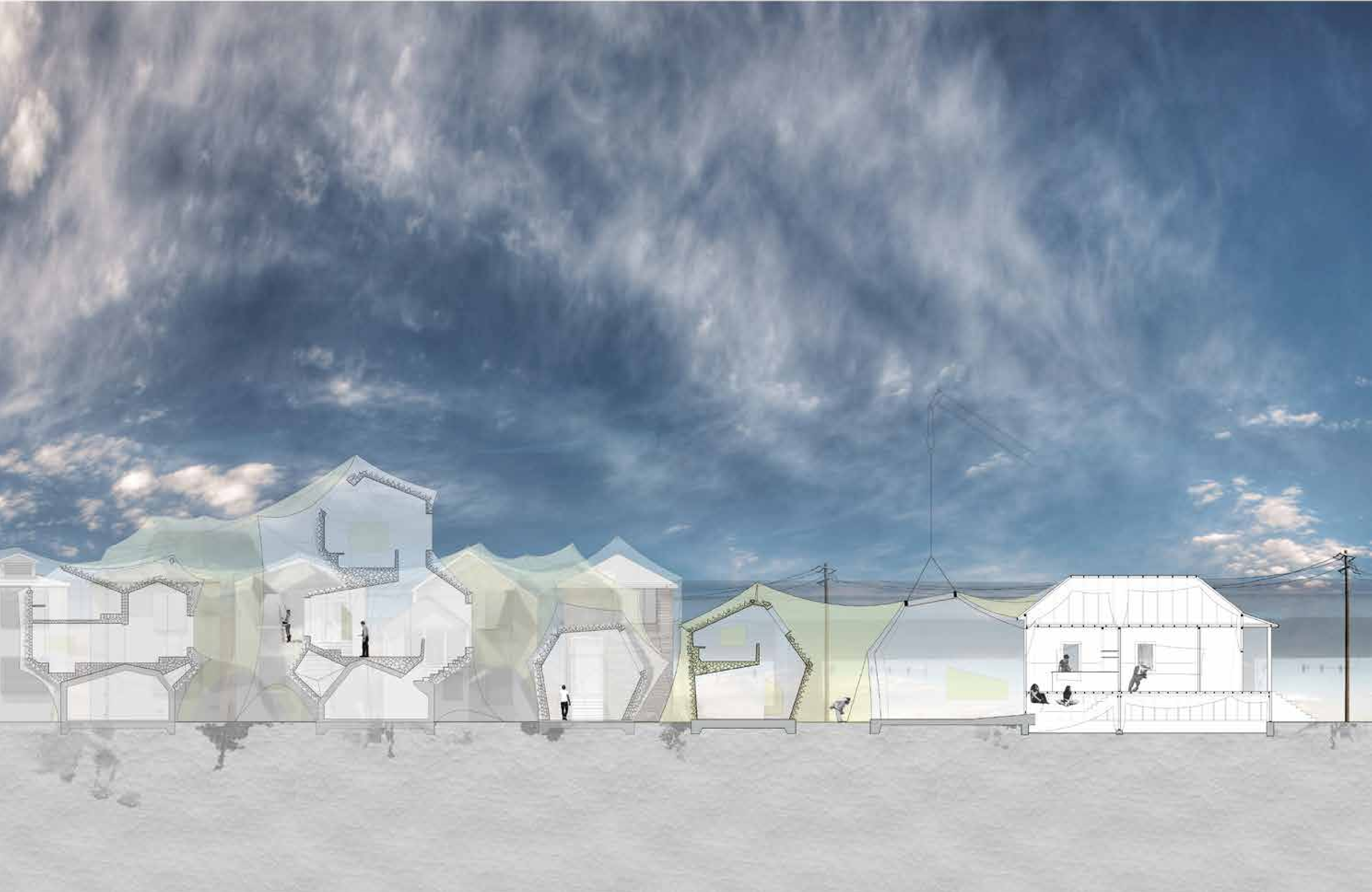
bacterial-plastic, beyond that is a layer of desiccated mycelium. Living mycelium adheres to dead, desiccated mycelium, and in this way new pods can be attached to the existing structure at multiple points. Rooms are grown and decayed at will.

The shade cloth necessary for the growing phase is retained for while the inner walls are desiccated and inert, the outer walls are maintained as living microbial gardens. Fungus farmers harvest mushrooms on shady apartment terraces, while kitchen and bathroom exhaust is filtered through living bacterial media. Each apartment has access to both the sunny, hydrocarbon filled outdoors, and the dank, humid, filtered microbial gardens. Usually shut off from the living space and accessed only a few times a day the microbial gardens proliferate. The wall section mediates between the dry and the humid conditions.

Shade cloths are strung from one home to the next creating shared humid spaces. The mega-microbestructure colonizes the entire block and soon the neighborhood. A fungal forest proliferates in the spaces between, on and around dwellings.



Top: Detail: drawing of a transforming home. Time shown with layered Plexiglas. **Bottom:** Detail: Dry and humid spaces. Cooking in the dry space, mushroom harvesting in the humid space.



Previous page: Layered drawing showing the neighborhood transforming over time. **Opposite page:** Model showing stretched shade cloth. **Top:** Model detail: humid and dry spaces. **Bottom Left:** Study model. **Bottom Right:** Section model.

RESEARCH

Over the course of the past year, I worked with several start up companies and researchers who I would like to thank for their assistance with this research. The experimental processes that I explored over the course of the year would not have been possible without their support of: Ecovative Design, Micromidas, Philip Ross, Daniel Fleishman, The Hyphae Design Lab and Back to the Roots. This work is also indebted to the Chester Miller Fund, which supported my travel to visit Ecovative's facilities in the winter of 2012.

The construction methodologies proposed in this thesis are in no way endorsed by these advisors, they are future oriented provocations that require further research and development before implementation.

Models showing formwork, humid growing phase, and desiccated phase.

Opposite: Fungus Wall, detail images taken over a 2 week period.
Above: Fungus Wall being misted in Wurster Hall, UC Berkeley.