CRETE house

INNOVATION

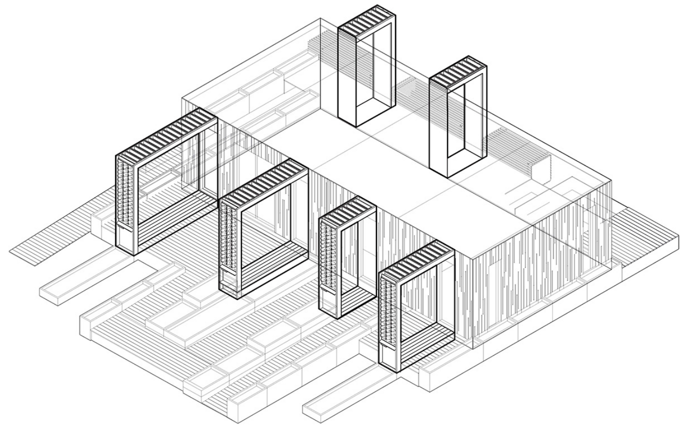
MISSION STATEMENT

The CRETE house is a model for advanced building technology, resiliency, and livability. The project is designed as a demonstration of integrated innovative precast concrete panelized system used in single-family homes, as a compelling alternative to traditional wood light frame construction. High Performance precast concrete structures are inherently resilient, protecting against fire, moisture and mold, insects, seismic events, extreme weather conditions and man-made phenomena such as blasts, force protection and acoustic mitigation.

Team WashU’s CRETE house developed from the belief that innovation comes from a holistic perspective on building technology, resiliency, and livability. This perspective starts with a building enclosure system that is inherently protective of its inhabitants. Our choice of UHPC (Ultra High Performance Concrete) on the outside face of the wall panels allows for a longer life cycle than typical construction materials; it utilizes a wall section which cuts down on material usage and weight, allows for a faster and more accurate construction process, and gains flexibility in design. Additionally, the design of the house focuses on self-sufficiency in terms of energy, water and food production, supporting a hydroponic system built within the gutter system of the house.

MASSING

The house is a 2:1 rectangular volume, with an east-west orientation. The north and south walls are modulated with concrete “gutters”, each of them exists as a displacement of the façade’s openings to create a transitional partially covered exterior space. This provides the residents with the opportunity to expand their living and working spaces out to the natural environment.



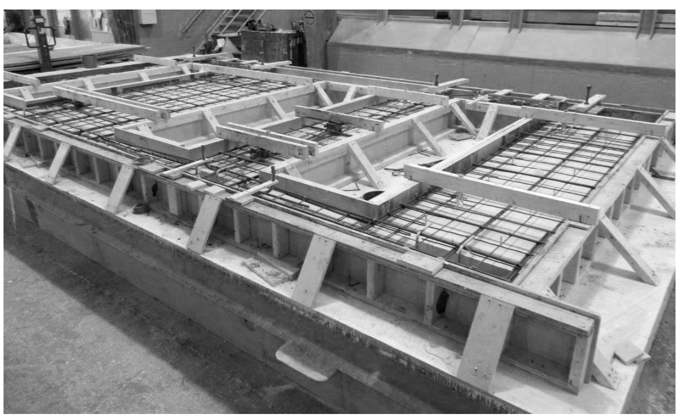
FRAMED OUTDOOR SYSTEM

Where the gutters are pulled out from the concrete box, full height windows and doors are placed allowing natural light and cross-ventilation through the short side of the massing. These openings have been carefully dimensioned and located to maximize thermal performance, daylight and resiliency.

Additionally, outboard of the windows CRETE house employs an exterior venetian blind system which, when closed, creates an additional layer of protection for the opening in addition to adding privacy and controlling glare and solar gain.

BUILDING ENCLOSURE SYSTEM

A successful building enclosure system performs at a variety of scales by a thorough integration of cultural, social, and environmental elements. The overall goal of a high-performance building enclosure is to lower operational energy consumption through design excellence of the enclosure. The performance of the building enclosure for the CRETE House is critical to the overall success of the building.



PRECAST CONCRETE PANEL CONSTRUCTION AT GATE

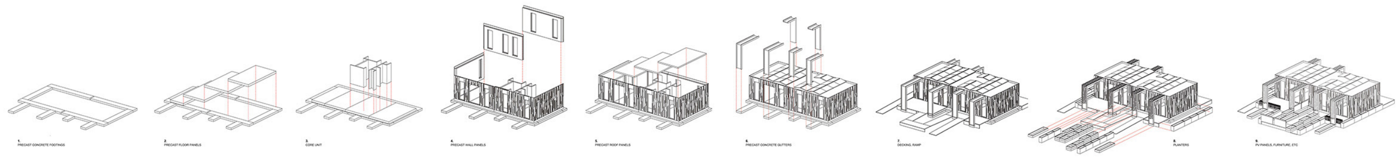
The team’s design consists of a precast concrete panelized system. Each concrete panel is carefully designed to maximize thermal performance and resiliency. The panels are robust, durable and insulated; manufactured in a factory and assembled on-site.

Dry connection methods using bolts are utilized, rather than traditional field welds, to make field assembly and disassembly faster and more efficient.

BOLTED CONNECTIONS

For this project, Washington University in St. Louis collaborated with the Precast/ Prestressed Concrete Institute (PCI) and specifically the following PCI Members: Gate Precast, Ductal Lafarge North America Inc., Dukane Precast, St. Louis Prestress Inc., Weiser, Lappco, Rocky Mountain Prestress, EnCon United/Stresscon Corporation and Ben Hur (Erectors). These companies were chosen to demonstrate the many innovative products and processes that are available through different concrete manufacturers.

ERECTION ON CAMPUS



ERECTION SEQUENCE

For CRETE house, the panelized approach involved manufacturing exterior (structural) precast concrete sandwich wall panels, composite concrete floor slabs, framing components, and decking which are then shipped to the building site for assembly. The precast components are assembled in sequence. The windows, doors, pre-cut electrical wiring and chases, lighting track racks, and all exterior finishing are highly integrated with the precast pieces. The house includes 32 structural precast components and multiple connecting points. The exterior shell of the house was erected in three days and about three days are estimated for all electrical wiring connections, HVAC, etc. The advantage of this approach is that it will greatly reduce the cost for the contractor and sub-contractors compared to the traditional approach, as well as allow for a considerable decrease in construction time and material waste and increase in overall construction quality.

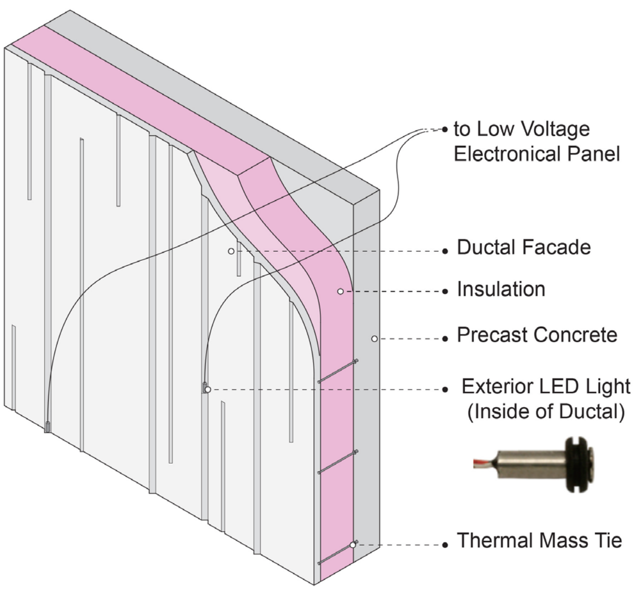
Construction process:

1) Install precast concrete footings and adjust levels for site conditions and topography.
2) Floor laid directly onto footing
3) Place pre-constructed core module on floor slab
4a) Erect the exterior structural walls in place on footing being held erect by temporary steel bracing
b) Erect two lateral walls create rigid structure
5) Place roof concrete sandwich panels to complete exterior envelope, caulk all connections to prevent water and air leaks
6) Attach exterior gutter components (vertical first, horizontal second) to footings and wall panels
7) Install decking and access ramps
8) Align planters with gutters
9) Apply finishes including furniture, interior finishes, planters, landscaping, etc.
10) Install louver system and photovoltaic (PV) panels

TRANSPORTATION OF WALL PANELS

UHPC

For CRETE house, Team WashU developed a precast concrete sandwich panel for the exterior walls, which consists of 4" of structural concrete for the interior layer of the assembly, 5" of foam insulation and 1.25" Ultra-High-Performance-Concrete (UHPC) on the exterior layer. Additionally, the exterior UHPC layer provides the possibility for unlimited configurations of geometries and variable thicknesses, which are not possible with traditional concrete panels. It also significantly reduces the overall thickness and weight of the wall as compared to traditional precast sandwich panels. This lowers the overall embodied energy as well as the cost and energy related to shipping the panels to the jobsite.



WALL ASSEMBLY, SANDWWICH PANEL

Team Wash U's exterior wall system was developed using Ductal, an innovative material which is a type of ultra-high-performance-concrete (UHPC). Ductal is a very dense, high quality cementitious material and it is defined by its exceptional high strength and durability.

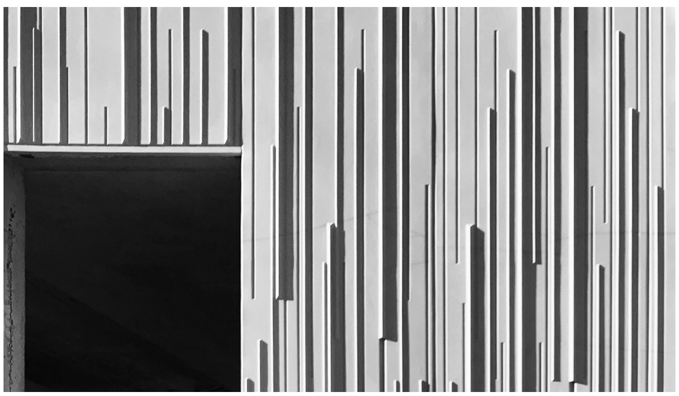
The material provides compressive strengths up to 29,000 pounds per square inch (psi) and flexural strengths up to 7,000 psi. Ductal is mixed with polyvinyl alcohol (PVA) fibers, and so, does not require steel bar reinforcing. It is six times stronger than traditional concrete which allows for thinner and lighter structures, less waste in production, and less greenhouse gases admitted when less cement is used. Due to its optimized gradation of the raw material components, UHPC is 10 percent denser than conventional concrete. Despite its weight being only slightly more than conventional concrete, a UHPC panel uses just one quarter of the material required for a panel made with conventional concrete due to its strength. Hence, the ability to produce more lightweight components with thinner, longer spans. Ductal's nanometer sized, non-connected pores throughout the cementitious matrix contributes to the material's imperviousness and durability against adverse conditions or aggressive agents. UHPC is also highly moldable - replicating texture, form, and shape with precision. Liquid or powder color pigments may be added and use of clear-coat sealants further protect finished surfaces from fading, surface staining, and graffiti. Overall, UHPC can be an exceptional material choice for innovative, attractive architectural precast elements that are extremely durable and lightweight.

The potential for building façades with a millennium-long design life (along with little to no maintenance and less environmental impact over time) is a huge paradigm shift from the way sustainable infrastructure is viewed today.

CRETE HOUSE SOUTH FACADE

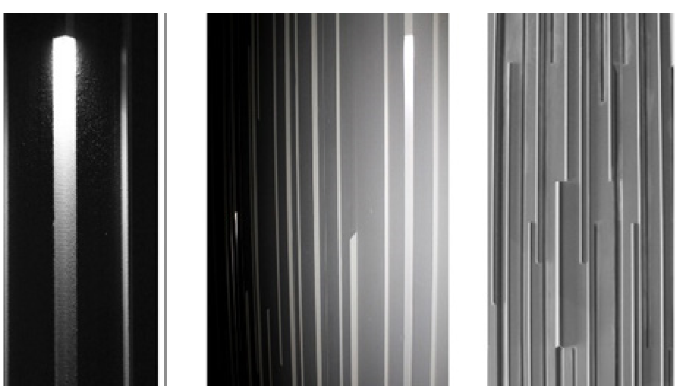
FAÇADE PATTERN AND INTEGRATED LIGHTING

CRETE house's unique pattern on the façade is possible when using a high precision material such as Ductal. The vertical patterning of CRETE house's exterior envelope presents a conspicuous notion of verticality in response to the strong presence of the tree trunks in the surrounding forest at the house's final site at Tyson Research Center. Varying in depth, width, and length, the reveals and ridges allow the exterior finish to become very dynamic, creating subtle shadows that constantly change throughout the day.



DUCTAL EXTERIOR WYTHE

The largest reveals, extruding 3/4" in and out of the surface, contains the exterior lighting integrated within the wall panels, small LED lights ¼" in diameter are placed pointing down and illuminate the grooves within the facade.



INTEGRATED LIGHT FIXTURES ON EXTERIOR ENVELOPE

When lit, these lights accentuate the facade pattern by creating slivers of light across the surface at night.

CONCRETE EVERYWHERE

The majority of the CRETE house is built out of precast concrete panels. The finishes have been developed based on the properties of the different types of concrete utilized in the project. The exterior envelope, as just described, uses UHPC with an off-white pigment. The ceiling is the underside of the roof, exposed form finished structural concrete. The Interior wall surface is mechanically troweled grey concrete finish, this type of finish provides a very smooth wall surface while exposing patchy uneven grey tones. The interior floor finish uses a lighter cement with exposed aggregate with a polished finish and a glossy protective coating. The kitchen island and countertop are also made of concrete with a dark pigment in the mix with a polished finish surface exposing the aggregates. For the surface of the central core, which contains the bathroom, kitchen, mechanical room and storage we are using a paneling system from TAKTL®, which is another type of advanced Ultra High Performance Concrete (UHPC). This product is very durable and exposes a very smooth and shiny white tone. It resists oil, gasoline, water, and UV rays providing a surface that is very easy to clean up with soap and water.

INTERIOR SHOWING MULTIPLE APPLICATIONS OF CONCRETE

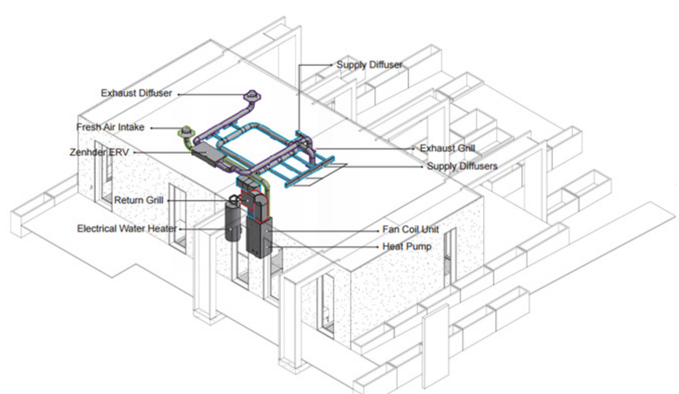
The team has also developed concrete furniture using GFRC (Glass Fiber Reinforced Concrete) as part of a course called "Furnish_It, with pieces" adapted for this competition; all exterior seating was designed and manufactured by students using white GFRC in combination with aluminum and bamboo.

STUDENT WORKING ON GFRC FURNITURE FOR CRETE house

As described, Team WashU chose materials that contain concrete with very different finishes and showcase the versatility and unlimited potential of concrete. We show that, with concrete, it is possible to deliver various finishes creating visual interest and harmony between spaces and components within CRETE house. In all cases, these finishes require low maintenance and demonstrate maximum durability.

THERMAL PROPERTIES

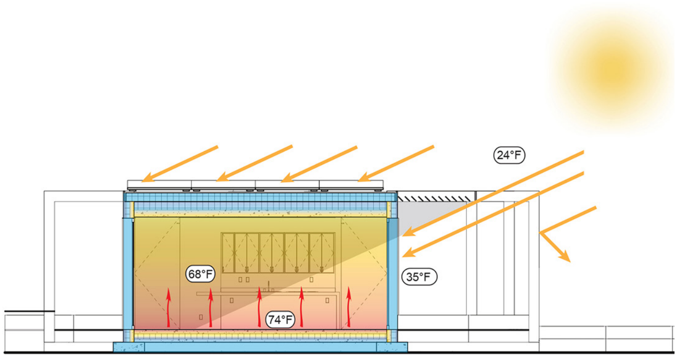
In precast concrete, the thermal mass acts as a balancing system to moderate diurnal effects from climate, allowing for novel control strategies with smaller mechanical equipment thereby decreasing the upfront cost premium of a concrete structure. In the CRETE house, the mechanical heating and cooling system is designed to meet peak cooling loads of 22,000 BTU/H (95°DB/76°WB) and peak heating loads of 14,100 BTU/H (5°F). These loads are met with a Hydro-Temp water source heat pump with a variable speed compressor that can provide 30,200 BTU/H of chilled water and 20,500 BTU/H of hot water at design conditions. The thermal capacitance of the concrete mass is 34,500 BTU/°F, allowing for a thermal advantage. For example, if the concrete is pre-cooled to 60 degrees in the summer and allowed to coast until 70 degrees, this is the equivalent amount of energy as 16 hours of peak cooling loads. Similarly, pre-heating the concrete slabs to 85 degrees and letting it drop 10 degrees is equivalent to 22 hours of peak heating loads. This capacitance inherently provides resiliency, survivability, and sustainability in the face of future power outages.



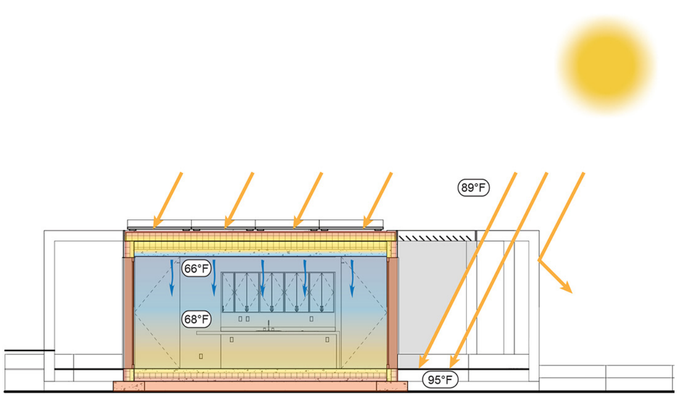
CRETE house MECHANICAL SYSTEMS

RADIANT HEATING AND COOLING

The mechanical system, located entirely in the house's core, uses two different modes for heating and cooling. The majority of the sensible heating and cooling loads are handled with the radiant tubing in the ceiling and floor, while a dedicated outdoor air system (DOAS) is used to handle the latent loads, ventilation, and any excess sensible heating and cooling loads. An Energy Recovery Ventilator (ERV) uses exhaust air to precondition fresh outdoor air before it enters the DOAS, capturing or releasing both sensible and latent heat.



RADIANT HEATING DIAGRAM



RADIANT COOLING DIAGRAM

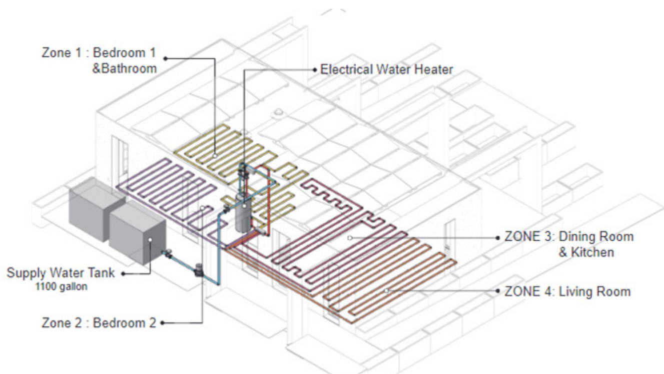
As noted above, mechanical heating and cooling systems are designed to meet peak cooling loads of 22,000 BTU/H (95°DB/ 76°WB) and peak heating loads of 14,100 BTU/H (5°F)*. These loads are met with a Hydro-Temp water source heat pump with a variable speed compressor that can provide 30,200 BTU/H of chilled water and 20,500 BTU/H of hot water at design conditions.

In Denver, the Hydro-Temp water source heat pump uses an 1100 gal storage tank as the heat sink/source to generate chilled/hot water for the hydronic system. Upon arrival at its final destination in Eureka, Missouri, the CRETE house will feature a permanent ground source heat pump.

The oversized system has the ability to recover heat for domestic hot water from the heat rejected during cooling. In the heating season, it operates to provide DHW (domestic hot water) on a priority basis. This means that the water source heat pump, coupled with a 60 gallon hot water storage tank, can provide 100% of the annual DHW energy requirements at much lower energy costs than all other methods available. With advanced, high performance buildings, the domestic hot water loads can outstrip the annual heating loads.

The radiant heating and cooling system is divided into four zones, each with independent control of water flow rates, and therefore, the load distributed to that zone. The hydronic floor is primarily used for heating, while the hydronic ceiling is primarily used for cooling. However, both surfaces can be used for heating or cooling if necessary.
Since condensation is a common issue with radiant cooling systems, CRETE house's building automation system (BAS) uses several measures to ensure no surfaces will reach the dew point inside the house.

During the cooling season, hot and humid outdoor air first enters the Zehnder ERV where the exhaust air from the building is used to precondition the outdoor air. The preconditioned air is mixed with the return air and sent to the DOAS, where the BAS controls the chilled water temperature and flow rate in order to deliver the minimum energy to cool down and dehumidify the air. The supply air temperature and humidity are calculated to produce space temperatures of 75°F and 50% relative humidity. At these conditions, the dew point is 55°F.



HYDRONIC FLOOR LAYOUT

Additionally, CRETE house has 30 total slab temperature sensors that feed information directly to the BAS. Based on the outdoor temperature and relative humidity, the BAS calculates the current dew point and ensures that the slab surface does not reach this temperature, in the event that the building is opened up and outdoor air is allowed to fill the space. If the floor is used for heating or cooling, these temperature sensors also ensure that the slab surface is within the comfortable temperature ranges according to the ASHRAE 55-2004 standard of 66.2°F-84.2°F The performance of CRETE house's innovative mechanical system is heavily dependent on a optimal BAS. The systems described here have several detailed sequences of operation, in order to carefully and efficiently manage the interior environment.

FRAMED OUTDOOR SYSTEM

In addition to creating a new outdoor space, the gutters that extend from the main volume of CRETE house perform multiple additional functions: working as a water collector, a vertical planting surface, a series of modular planter beds supporting a hydroponic system, and a sunshade for the corresponding windows behind.

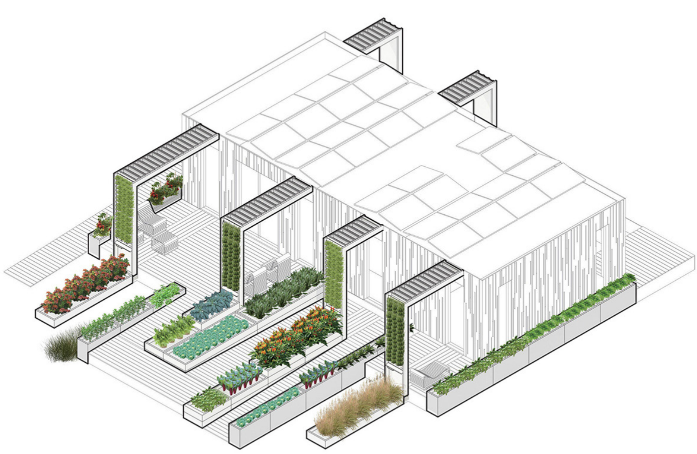
The gutters and planters as a collective unit will serve as a productive device allowing for the cultivation of vegetables for consumption, while also serving a formal role as safety and privacy barriers for the inhabitants and their visitors.

The flexibility of the design is reflected in the maintenance of these horizontal and vertical green elements as they can be as much or as little of a time and financial demand as the user sees fit, with full capacity planters allowing the owner to grow enough food to accommodate a basic diet, and low capacity planters allowing for minimalist landscaping.

HYDROPONIC SYSTEM

CRETE house will demonstrate a community collaborative food supply through a home garden system. As part of a sustainable lifestyle the house will provide nearly year-round vegetables, fruits and spices cared and harvested by the residents. If this house were to be integrated into neighborhoods within St. Louis, a sustainable edible garden could be a place of community, collaboration and self-sufficiency for food deserts (areas that do not have quick access to produce and grocery stores). Implementation and influence of our house within St. Louis neighborhoods is a long-term goal by nature of its prefabrication and modular capabilities.

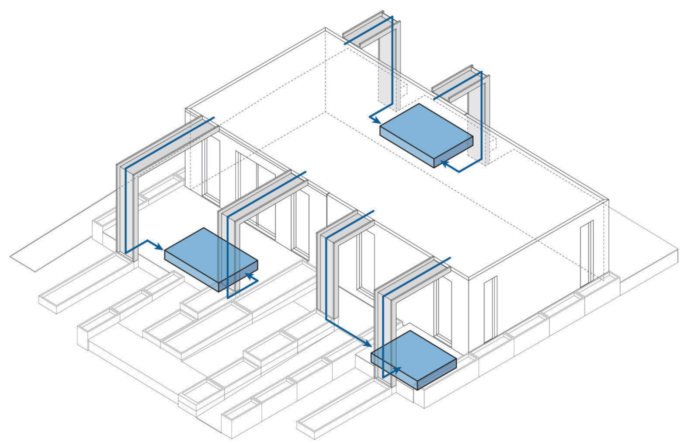
However, the permanent location of our first house, after the competition, will be at Tyson Research Center right outside the city of St. Louis. At Tyson, the house will accommodate researchers living and working at the ecological center. The landscaping and edible gardening may remain or adapt to the needs of these residents. For example, the plants may alter to species the researchers are examining or trying to preserve.



EXTERIOR PRODUCTIVE LANDSCAPE

WATER COLLECTION

A rainwater harvesting system is implemented to collect water, the roof drains the rainwater down towards the six concrete gutters. This water is collected into storage tanks underneath the decking and it is pumped to the plants providing an integrated drip irrigation system along the vertical growing medium and the horizontal planters when needed.



WATER COLLECTION / STORAGE SYSTEM

LIFE CYCLE

In addition to reducing operational energy consumption, concrete buildings are resilient, reducing total embodied energy and environmental harm. The frame of a wooden house is commonly composed of softwood 2x4's with a minimum average life expectancy of 30 years.[1] However, concrete buildings have an estimated lifetime of more than 100 years, about three times longer than that of a wooden house.[2] This constitutes a major advantage to both CRETE house and the environment alike, while demonstrating the viability and the environmentally friendly benefits from the materials design.

[1] Seiders, David , Dr., et al. "Study of Life expectancy of Home componentS." Lafarge.com. February 2007. Accessed July 13, 2017. http://www.hbact.org/Resources/Documents/Files%20L-Z/Life%20Expectancy%20of%20Home%20Components%20-%20NAHB.pdf., 4.
[2] "High-performance precast concrete for 100-year life span in Kansas City." Lafarge.com. December 03, 2015. Accessed July 13, 2017. http://www.lafarge.com/en/high-performance-precast-concrete-100-year-life-span-kansas-city.

EMBODIED ENERGY

CRETE house's unique precast wall panel design cuts down on the typical embodied energy of structural concrete by eliminating waste through the slimmer wall section, increasing the strength of the material to withstand natural disasters, and finally, by increasing the resiliency of the building allowing it to last for many years to come.

The embodied CO2 of CRETE house was quantified through a life cycle analysis. This primarily included the structural aspects of the house including the concrete, insulation, steel, doors, windows, and plaster. Other aspects were not quantified because they are similar between the houses. In the end, CRETE house tallied a total of 49,000 kg of CO2, with over 50% from concrete. A wooden house of the same size only emits 32,000 kg of embodied CO2. CRETE house, despite its higher embodied CO2, only takes around 1.5 years to start becoming more environmentally friendly than a wooden house. This is due to the extremely low operational carbon footprint of CRETE house. When considering that CRETE house lasts three times as long as a typical wooden house, the environmental benefits of concrete as a building material truly come to light.[3]

[3] Monahan, J., and J.c. Powell. "An Embodied Carbon and Energy Analysis of Modern Methods of Construction in Housing: A Case Study Using a Lifecycle Assessment Framework." Energy and Buildings 43.1 (2011): 179-88. Web.