ARCHITECTURE

U.S. DEPARTMENT OF ENERGY
SOLAR DECATHLON

UC DAVIS

Architecture Jury Narrative

Our H_2Ouse. Our Water Use.

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Our Story

With its second entry into the Department of Energy Solar Decathlon, the University of California at Davis (UC Davis) is proud to continue its history of appealing design and student-driven engineering, with its new team name: the Blue Mustangs. Since its inaugural entry in Solar Decathlon 2015, UC Davis has capitalized on the project as an opportunity for students to explore designs that can address a need. For the agriculturally-focused UC Davis, the lack of suitable housing for migrant farmworkers was a social and environmental problem that felt close to home. To address this problem, the 2015 entry “Aggie Sol” presented below market-rate zero net energy (ZNE) housing, featuring night-time radiant cooling via rooftop sprinklers and a purpose-built floorplan catered to low-income agricultural workers. For the 2017 home, defining the problem scope and determining how the Blue Mustangs could address the problem was be the starting point. Amid a severe drought in California in 2015, the problem seemed obvious, but refining the problem scope and how to tackle such a problem was an extensive and iterative process. Eventually, "Our H_2Ouse" (pronounced “Our House”) arose. Similar to the UC Davis 2015 entry, we continue the philosophy of addressing environmental and social needs. Our H_2Ouse balances innovative and experimental systems with simple and adaptable implementation designed around our three pillars: to be drought-resilient, educational, and inclusive.

Our State

California has the largest population in the United States as well as the largest agricultural output[1,2]. This plethora of people, animals, plants and machines can require anywhere from 50-100 million acre-feet of water annually[3]. To sustain such high levels of organic and inorganic activity, California produces the second largest carbon footprint in the U.S.. However, California’s per-capita emissions are the third lowest in the nation. Although the environmental burden of California is high, its low per-capita emissions is a testament to the cognizant and progressive nature of Californian residents. Although California continues to lead standards and innovations in terms of environmental and technological platforms, to maintain the Californian lifestyle the status quo in California must evolve to meet the challenges of the future. The Governor of California, Jerry Brown, announced the "end of the drought" in April of this year; however, California’s struggle is far from over. With the cyclical nature of the drought events in California, combined with the continued growth and development of the state's population and cities, the need for sustainable and renewable water and energy management will only grow more pressing. In the past 5 years, numerous state government initiatives have responded to these looming issues, largely by setting long-term goals for water and energy reduction and incentives for renewable energy, and water production and use.

Many of these initiatives (listed on the left) involve increases in resource efficiency use within the residential sector, which while exerting some of the smallest consumption rates, has great potential for effective conservation strategies[4,5]. Although technological advances can increase efficiency, California demonstrated the importance of user behavior during its most recent drought. With state-wide mandatory conservation, Californians successfully reduced their urban water consumption by 25% in 2016, and Jerry Brown called on California's population to "make water conservation a way of life", rather than a temporary practice. California needs to evolve so all residents have the knowledge and ability to conserve their water and energy use, and the means to implement crucial lifestyle changes. Our H_2Ouse embodies this goal by providing an affordable residence that is dedicated to occupant engagement and education and providing a powerful tool to cultivate a water and energy conservation lifestyle.

Our Vision

Recognizing the water and energy problems plaguing California, the Blue Mustangs developed Our H_2Ouse to create feasible and desirable homes using California-specific strategies. This house is an inclusive, drought resilient home, and provides salient information feedback for its residents. While Our H_2Ouse displays new and innovative technology it also works hand-in-hand with current technologies.

Our H_2Ouse addresses the most pervasive and unpredictable factor in energy and water savings: user behavior. The virtually untapped resource of user behavior modification can exploit the efficacy of "smart" technologies by modifying the user inputs associated with such technologies, thus bridging the gap between the potential water/energy savings and the realized water/energy savings. Addressing this resource reduction for one home through user behavior requires motivation through education and salient reminders that facilitate long-term lifestyle changes, but to truly impact reduction — reduction that reaches beyond one home and begins to address a growing problem — there must be statewide collective action. Because Our H_2Ouse has been designed to support a wide-range of housing applications, it is the hope of UC Davis students and faculty that Our H_2Ouse can continue to promote drought-conscious and innovative residential development while decreasing the environmental impact of the residential sector.

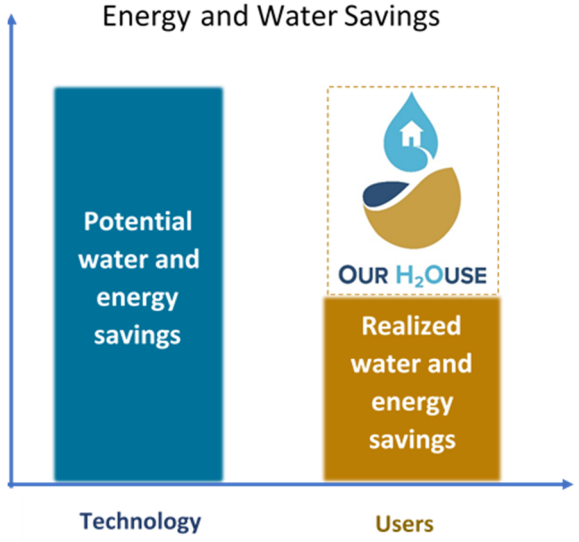

Figure 1: Our H_2Ouse bridges the gap between potential and realized water/energy savings by addressing the user in addition to just the technology

Our H_2Ouse responds to California drought events with water efficient technology, drought-tolerant landscaping, and water-conscious interior design.

Our H_2Ouse educates occupants through feedback mechanisms salient systems, and intentional design.

Our H_2Ouse is feasible for a wide range of residents, with full ADA accessibility, low-cost solutions, and reconfigurable features.

Our Research & Development

Independent Prototyping

The process began with one class: ECI 126 or Green Building. This class was taught by the faculty advisor for the Solar Decathlon, and featured guest lecturers in architecture, sustainable practices, and current innovative technology. The class focused on informing students about the status quo in building, and the problems associated with traditional building practices. It provided a framework and tools that future decathletes would later use for the Solar Decathlon effort. Students began building a working knowledge for building materials and passive solar techniques, as well as practice with energy modeling, scale modeling, and 3D modeling in Revit. Eventually, the class was divided into three groups, and each group designed their version of a successful decathlon home. These designs were modeled, prototyped, and competed against each other. This mini competition gave rise to the Ed House, focused on educational feedback. Competition concerns, like transportability and a desire for modular building, brought our design to two simplistic and offset living modules. In the midst of mandatory conservation measures on our very own small town, a growing desire to address our drought-stricken region gave rise to an expanded focus which blended education with water conservation; thus Our H_2Ouse was born.

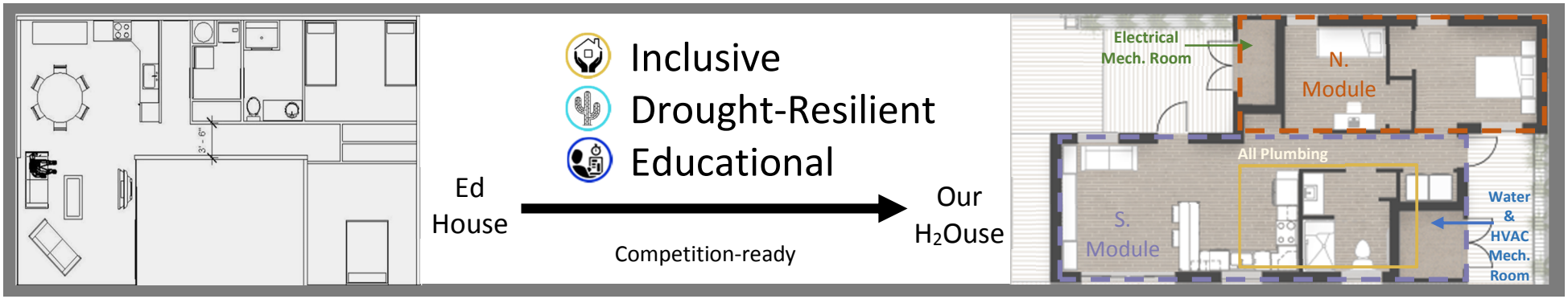

Figure 2: The design process was an iterative one, where the three pillars were refined and competition logistics were taken into consideration.

Collaboration

With a working design, students were split into teams, such as building design, landscape design, water, electrical, and energy modeling. The innovation process began with students familiarizing themselves with the current range of innovations that existed. This involved extensive online research, usually conducted by reading research papers. As research was performed, all findings were assembled and organized on a cloud-based file sharing system so that they would remain accessible to all current and future team members. Perhaps even more beneficial was the communication with relevant on-campus research groups which included the Center for Lighting Technology, the Center for Water-Energy Efficiency, the Western Cooling Efficiency Center, and the Center for Watershed Sciences. Professional architects, designers, and marketing professionals were consulted throughout the process for constructive criticism and professional guidance. In addition to these exchanges, students witnessed innovative technologies in action at various on-campus buildings, including the Honda House, Jess S. Jackson Sustainable Winery Building, and the 2015 Aggie Sol. These exchanges and building tours gave inspiration to students, sparking investigation of different avenues of research, and helping to form the basis for innovative features in Our H_2Ouse.

Our H_2Ouse

Building Floorplan

From the outset of the design process, our building design team agreed that when it comes to housing, the phrase "bigger is better" is fundamentally flawed. Bigger buildings require more materials, more water, more energy, and have a higher risk of possessing dead spaces and features that go relatively unused by occupants. With this in mind, one of our main challenges became how to make a small home feel open and unrestricted.

Figure 3: North deck rendering showing the front entrance to Our H_2Ouse

Our H_2Ouse features a ranch-style, modular floorplan of just over 900 ft^2 of finished interior space, mirrored and wrapped by about 1200 ft^2 of shaded outdoor living, both of which feature code-compliant ADA-accessibility and coherent design. Both the East and North deck feature separate mechanical rooms, with the North module housing the electrical mechanical room, and the South module housing the water and HVAC mechanical room (see Figure 2 above). This modular design allows for easy equipment room access and short and centralized plumbing runs, needing only to service the South module, which increases efficiency of water transport. In addition to increasing efficiency, the separation of water and electrical equipment adds an additional safety measure. While not originally a main theme of Our H_2Ouse, the home is non-traditional in look and feel. It does not hide its inner systems from the minds of the occupants and their neighborhood, but provides prominent reminders to the occupants and their community of the water and energy systems that make the home function. This can promote water efficiency through increased occupant awareness of the amount of resources they require for a comfortable lifestyle.

Interior-Exterior Dynamics

To increase market appeal, Our H_2Ouse features a simple, open spatial arrangement focused around one large public space, split between the exterior and the interior. This space includes the kitchen, living, and dining room, with the latter two spanning the interior/exterior boundary for most of the year. To the east, this main living space leads into a hallway that branches off into a master bedroom, second bedroom, bathroom, and laundry closet, and terminates at a near floor-to-ceiling glass door which opens onto a covered east privacy deck. This eastern private space is connected to the south public space by a walkway which connects to the north entry deck and the entry and exit ramp. Interior and exterior connection is aided through consistent use of industrial modern-rustic finishes throughout both areas. Modular, multi-functional and reconfigurable furniture can be rolled between living spaces and supports a variety of private and public event

formats. Carefully selected windows and door placement increase the visual integration between the two spaces, and wrapping the interior with the exterior space allows for easy circulation through and around the entire home.

Re-configurable and Adaptable

The adaptable nature of the home allows for increased utility and integration of different living spaces, depending on resident behavior and preference. Depending on what spaces occupants want to use, furniture can be rolled from one place to another and locked into a temporary position. The most important piece of furniture with this capability is the accordion table, which in its compressed state can seat three individuals, yet in its fully expanded state can accommodate up to ten people using three removable table leaves. To provide this amount of seating, nine rolling ottomans can also be easily redistributed through the home. These ottomans are dually functional by having two-sided tops: one side houses for ottoman cushion and the other a smooth flat surface. This allows for versatility in each unit, as the occupant can switch between a seat and a side table whenever desired. These units can be locked together to serve as additional large seating and table areas. When not in use, the units can be stored under the accordion table or within the built-in cabinetry in the main living room, where their presence is concealed by two folding tables that can provide additional working height surfaces. Above the built-in cabinet lies a soffit, whose cavity is used to stow a projector screen which can be withdrawn for video watching or large-format computer work. All other audio/visual equipment can be placed in a concealed or exposed manner throughout the rest of the cabinetry or pegboard-style shelving. The exterior elements are more static in nature, but still allow for diverse utility. The modular south deck shade structure features a series of shade cloth screens that are easily adjustable, and the underlying bench and deck provide an easily divisible and customizable sitting and standing area.

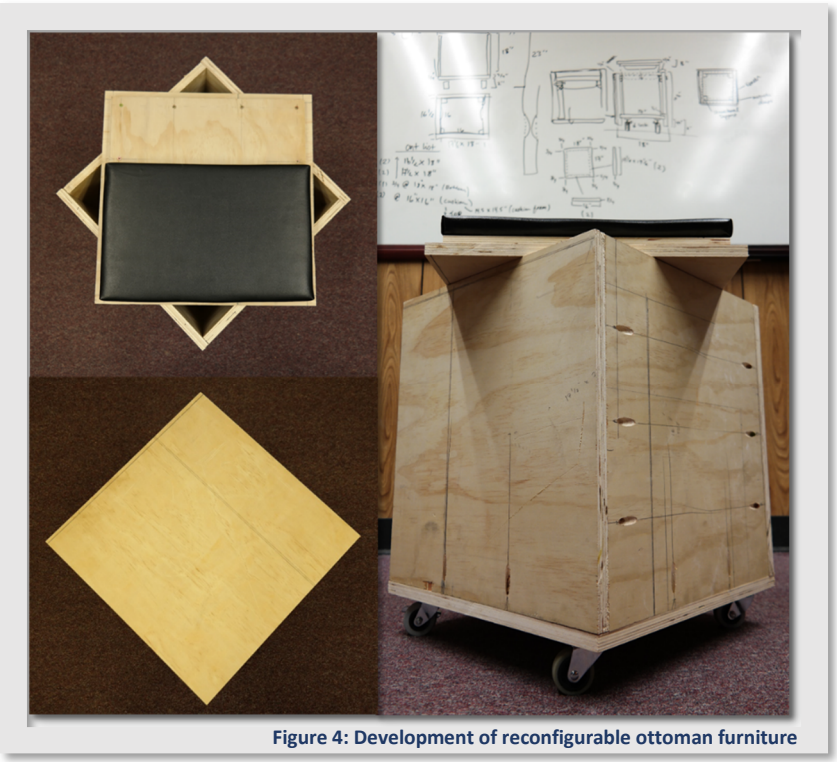

Figure 4: Development of reconfigurable ottoman furniture

Lighting and Energy

Our H_2Ouse solves the problem of balancing natural light infiltration and energy efficiency with the use of super-insulated walls and dynamic window glazing. The building envelope is comprised of 12" wide exterior and 5" wide interior BamCore® wall systems, both of which feature a framing factor of 2.5%. Combined with OSB/polyurethane SIP roof and floor panels, these unique features can significantly reduce a home's operational carbon footprint due to significant reduction of the heating and cooling load placed upon the home's HVAC system. Inset into this unique wall structure are a series of windows and doors that make use of triple glazing with LoE^3-366 coatings. With at least one of these windows or doors in each room, all interior spaces are provided with uninterrupted views to the exterior as well as natural lighting. In lieu of window overhangs, Our H_2Ouse experiments with a more responsive and dynamic south shading approach that in-part involves solar

intuitive, thermochromic window filters. These filters automatically transition to a tinted state during hot conditions to manage solar heat flow, glare and UV degradation and clears during cold conditions, therefore harvesting solar heat flow and light. In addition to this strategy, the shade structure also provides manually adjustable shading options to the house and the south deck living space. During times when natural light is no longer adequate, dimmable interior and exterior LED fixtures can provide supplemental illumination. All LEDs within the home respect circadian rhythms by producing majority blue and red light during the day and night, respectively. In addition, recessed and indirect floor and ceiling lighting are automatically activated during the night via a motion sensor for easy and safe mobility throughout the home. When in use, the lighting energy as well as other energy sources in the home can be monitored by the home's energy monitoring system and displayed back to occupants in the same influential manner as water consumption information is displayed. Energy use is monitored and analyzed by the home's Sunverge Integration System (SIS), an all-in-one system that features battery storage, a solar inverter, and a cloud-based energy monitoring and management system. This feature of the device is incredibly important as it provides Our H_2Ouse the capability to dynamically modulate energy production and distribution to the home or the grid (net metering). In addition, the SIS allows for information sharing among multiple homes and makes this information easily accessible to utility companies and government agencies. It is our hope that with this increased collection and dissemination of information, stakeholders can better understand and regulate their current needs and associated usage, as well determine trends and practices that can help them move to a more resilient and responsive state-wide energy grid.

Buildability & Transportability

Inspired by the best attributes of manufactured homes, Our H2Ouse features a wide range of prefabricated and modular building strategies to be widely deployable and easily installable. The house is built on two double-wide trailers, with a north and a south module on each trailer. When the home is ready for transport, the trailer is simply connected to freight trucks and pulled to its destination. The trailers allow for easy separation and merging of the two modules. While this format of home building has historically been regarded as lower class, the recent popularity of the “tiny” house has reduced that stigma, paving the road for easy transportation options in a wide variety of areas and terrains. The trailer frames allow linear assembly line building processes to smoothly occur within controlled-environment building facilities, minimizing the total assembly time and building costs, and protecting the home's assembly from moisture, insects, and other hard to control environmental factors. Assembly time is further reduced by using fully panelized roof, walls, and floors. Standard OSB/Polyurethane SIPs can be rapidly set and connected

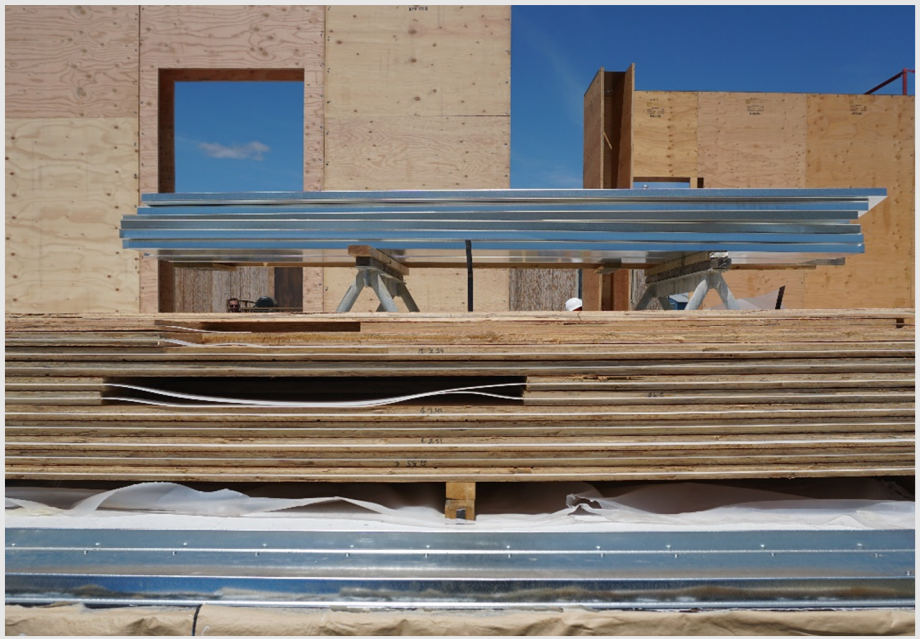

Figure 5: Close-up of BamCore® panelized Prime Wall® System

with the use of a quick-drive screw gun and wood splines, or (even faster) foamed in metal camlocks that allow for near-zero thermal bridging within the assembly. The walls are based around a panelized construction and set in place and connected with stainless steel tracks and splines. An additional benefit of this installed system is the near stud-less cavity that allows for electrical and plumbing lines to be easily run without the need for drilling through studs and blocking. The home's single wet module also means that all interior plumbing connections can be made before transport and helps reduce heat losses and cost from hot water lines. In addition to adhering to the home's industrial modern-rustic aesthetic, finish materials and their installation are durable, verified to be able to survive thousands of miles of transport along bumpy roads. By heavily relying on multiple methods of prefabrication, Our H_2Ouse utilizes panelized systems to drive cost and assembly time, capitalizing on the speed and versatility of manufactured homes, while not sacrificing in quality and innovation of building materials, nor aesthetic appeal.

Information Feedback Devices

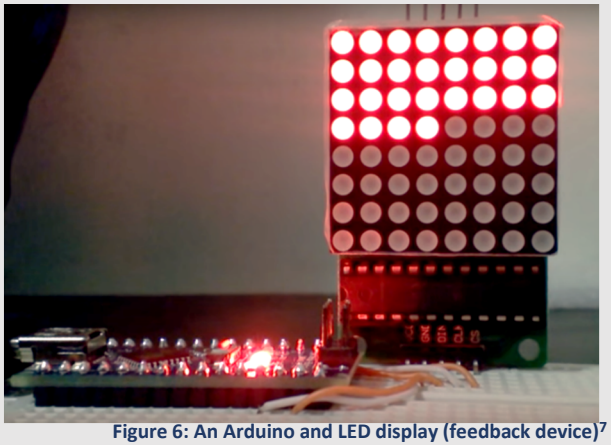

Figure 6: An Arduino and LED display (feedback device)[7]

To overcome occupant indifference and establish a salient reference point for appropriate and adequate water use, Our H_2Ouse features unique occupant-level and community-level devices which show real time water consumption. The most prominent occupant-level interior device is a tablet-based heads up display (HUD) that presents water (and energy) use summaries in easily customizable formats and layouts. However, the tablet itself is integrated into the home by placing it behind a piece of two-way mirrored glass in the bathroom vanity. In this format, occupants are greeted by information summaries while looking at themselves in the mirror in the morning and night. The tablet is easily removable and can be carried-to and placed-in any other alternate areas of the home depending on occupant preference. While the tablet does afford the occupants some control capabilities over the home's energy and water management, the primary purpose is to regularly engage occupants in recognition of their energy and water use as well as the broader environmental and economic implications of their resource consumption. The remaining interior devices involve visual light feedback. Real time water meters placed in visible proximity to the kitchen and bathroom sink are powered by an Arduino microprocessor which calls data from water meters and illuminates sequential individual LEDs to allow occupants to gain instant understanding of the amount of water they are using (see figure 6). Another interior LED feedback device is integrated into the Hydrao® showerhead that changes colors with differing shower durations. The thresholds and colors can all be customized by the occupant from their smart phone. These feedback devices transform water use from an unconscious action into a more thought-provoking and conservative activity, resulting in individual behavioral changes— changes that the Blue Mustangs are confident will permeate beyond the walls of Our H_2Ouse and influence conservation on a much grander scale.

The sole exterior device is a dynamic water feature purposely made visible to the passersby, located at the front of the house on the north side entry deck, and unlike traditional fountains, loses negligible liquid to evaporation. This feature directly relates to the home's total water consumption compared to an average household's total water consumption. The ambient, eco-feedback display mimics ecological processes, such as the filling and draining of reservoirs, providing a more physical and relatable depiction of water conservation. The occupants are rewarded with this dynamic water feature when they save more water than average. Rewarding such positive behavioral changes motivates occupants and can be a catalyst for a friendly neighborhood challenge, turning household occupants into a conservation team and increasing both inter-household and neighborhood accountability. Our system could be upscaled with water features for individual

houses as well as a hub for a neighborhood-level water feature which aggregates all water-saving data, allowing neighborhoods to team up and challenge other neighborhoods to this "conservation game". Our H_2Ouse not only engages its occupants in water conservation, but the whole community. The Blue Mustangs are confident that behavioral changes and a cultural shift towards a new water conservation status quo can be inspired with collective action and see success much like that of the exercise technology, Fitbit®—just replace steps with drops.

Aesthetic

Exterior

The water-themed industrial modern-rustic aesthetic of Our H_2Ouse is visually representative of an appropriate home for California residents. On the exterior, a combination of corrugated steel and exposed wood grains simultaneously simulate the contrast between land and water as well as blend modern and rustic aesthetics. Dotted throughout the exterior exist many unique and eye-catching water-themed flourishes including landscaping consisting of blue grass, a dynamic water feature on the north side of the home, and large cross-sections of tree trunks from trees killed by the drought. The staggered rectangular house modules and deck features create simple, linear geometry that is cognizant of modern building design, and with a constant angle of 1/2:12 the roofline of Our H_2Ouse maximizes its rainwater collection area and recalls the uni-sloped roofs of traditional and modern passive buildings, as seen at UC Davis's flagship planned ZNE student housing community, West Village. As the home is intended to be permanently sited near West Village, other design decisions were also made to mirror its aesthetic, including the use of corrugated steel as a main siding material and composite wood planks as decking and railing. In addition to thermochromic window glazing, additional southern shading is provided by a large timber-framed shade structure whose accent components include industrial black steel pipe bracing and un-tensioned, neutral tone shade fabric. Under this structure stretches a near 30' long bench, whose substructure is composed from the steel frames of the home's intermediate bulk container (IBC) water tanks. The biophilic needs of occupants are provided for in the low-lying planter boxes that wrap around the North, South and East side of the deck perimeter, and are filled with plants that are able to provide a lush, natural plant color palette while requiring minimal irrigation. Although Our H_2Ouse is built in the fashion of a manufactured home, the exterior finish and features make it clear to passing competition visitors that it supports a lifestyle more sophisticated and intriguing than anything commonly offered within that industry.

Figure 7: Installing Tyvek® and a rainscreen system

Interior

The interior of Our H_2Ouse is cohesive with the industrial-modern rustic aesthetic that is established on the exterior. Main accents include both natural and composite exposed wood grains as well as black steel pipe and water-themed finishes and decorations. Within all main living spaces, stained and unstained wood colors vividly contrast with the off-white walls, ceiling and counter tops. The single flooring

material mimics aged and distressed wood planks by combining light brown and grey wood-grain patterns, ultimately providing the home with the natural, cozy feel that hardwood floors offer. Cabinets, shelving, furniture, and fenestration shadow trim are constructed from the same droughtwood as the exterior accents, transforming a negative past impact of the drought into a beautiful and present interior finish, yet still serving as a reminder for the necessity of future change. Exposed ceiling were resawn to provide an additional weathered appearance. Exposed fire suppression piping and decorative black steel pipe, used as supports for moveable shelving and an accordion table, provide the industrial component to the building's aesthetic. Exposing the fire suppression system and providing water-themed finishes reminds occupants of the systems within the home, pushing back against the notion that such systems should be hidden. Instead of "out of sight, out of mind," Our H_2Ouse brings the system back into conscious thought, to increase awareness of resource use. The main brown and white color palette is accented by various shades of blue used in water-themed artwork, as well as brushed metal finishes of home appliances and water fixtures. The cumulative result of this aesthetic is an interior that feels clean, open, and inviting, and would offer occupants a sense of living that is modern and innovative, yet recognizable and intuitive.

Figure 8: Master bedroom featuring droughtwood bedframe and rollable ottomans

Materials

Material selection for Our H_2Ouse involved careful life cycle analysis with emphasis placed upon sustainable sourcing and long-term cost-effectiveness. Finish materials were given the added requirement of adhering to the industrial modern-rustic aesthetic and/or the theme of water-relatedness. Ultimately, the selection criteria resulted in utilizing a diverse range of materials that offered long-term environmental and economic benefits.

Metals

Several types of metals were used in and around the home, but most prominent is the extensive corrugated steel siding used on the home's exterior. Finished with Kynar 500 paint system, this siding blends the rustic form of corrugated metal siding with a modern matte color. Steel siding possesses high recycled content, is incredibly durable, and can be easily reused at the end of its life cycle. In addition, Kynar 500 coatings are fluorosurfactant free, contribute to LEED accreditation, and can possess a solar reflectance of over 70%. Other exterior metals play less of an aesthetic role, but provide valuable structural integrity to architectural features including the southern shade structure and bench. Black steel pipe is used as horizontal bracing between shade structure beams, which in-turn support the shade cloth and track system. Even more "behind-the-scenes" are the steel frames of each IBC that act as most of the home's water tanks. Designed to resist loads encountered during trans-oceanic transport, these steel frames make the IBCs able to function as the substructure for one of the home's

main exterior architectural features. In addition, these reclaimed IBC's are modular, easily transportable, and incredibly cost effective at a price of around $120 per (reclaimed) unit. The role of interior metals is again more structurally focused. Black steel pipe is used as a support component in shelving throughout the house, as well as in the frame of the accordion table. Completely hidden from view is the aluminum panels used in the home's Warmboard-R radiant heating and cooling panels, which allow the radiant system better heat distribution and responsiveness compared to concrete. In conclusion, both the form and function of metals are utilized throughout Our H_2Ouse, and help to make a cohesive and comfortable living experience.

Wood

Figure 9: South deck bench framing supported with IBCs

California is home to 33 million acres of forest, much of which suffered greatly during the latest drought. More than 100 million trees were unable to survive the widespread water shortages and thus perished, creating a significant fire hazard. To cope with this disaster, a company named Forest Innovations was created with the sole focus of repurposing these dead trees into usable lumber. It is this lumber that is featured extensively throughout the interior and exterior in its bare, unstained form. On the exterior, this "droughtwood" is used to accent the corrugated metal siding. The wood is also used for furniture and shadow trim for the home's window and doors. By using this wood, Our H_2Ouse helps to make the best out of a tough situation, and pays homage to the tragedy that was the last California drought and the trees whose lives it claimed. As previously mentioned, near stud-less bamboo panels form the majority of the walls within Our H_2Ouse and provide high levels of thermal and acoustic insulation. Bamboo is more sustainable than traditional framing lumber due to the nature of its production. Compared to common lumber species, bamboo requires less fertilizer and nutrients to grow, and possesses a faster growth rate and higher growing density. Because this wall system uses more wood than traditional framing methods, it also works to permanently sequester more CO_2 from the atmosphere. Ultimately, these attributes make BamCore worth the higher upfront cost due to its diverse environmental benefits and the long-term energy and economic savings it provides through reduced HVAC heating and cooling loads.

Polymers and Composites

Cleverly hidden and artfully disguised polymers and composites are utilized throughout the interior and exterior of Our H_2Ouse. The decking is a 95% recycled sawdust/plastic bag composite, whose production chain recycles 100% of factory runoff and refuse back into the original manufacturing line. Completely out of sight is the TPO cool roof membrane which helps reject solar heat gain and can be easily recycled at the end of its first life cycle. Although often compared to PVC, TPO contains no plasticizers, demonstrates better resistance to long-term UV damage, and meets the criteria of LEED and Energy Star. Indoor polymers include Corian countertops and backsplashes as well as replica wood flooring that has passed the FloorScore test, a comprehensive US certification system for floor coverings based on LEED point scorings. The utilization of these composite and polymer materials afford the interior and exterior of Our H_2Ouse increased long-term durability and high-quality appearance, while keeping in line with the home's overarching industrial modern-rustic aesthetic.

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Appendix: Architectural Photography

Figure A1: Interior kitchen view facing East

Figure A2: Kitchen and living room perspective view

Figure A3: Living room west facing view

Figure A4: BamCore® installation perspective

Figure A5: Hallway view

Figure A6: South deck view of bench and IBC structure

Figure A7: North view of BamCore Wall system installation