



enable

Your home for today,
and tomorrow

Innovation Narrative D8 Submission

August 10, 2017

HOUSE

by Northwestern

Northwestern University

U.S. Department of Energy
Solar Decathlon 2017



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**innovation
narrative**

INTRODUCTION

Enable by House by Northwestern is Northwestern University's first entry in the DOE Solar Decathlon. Designed for active Baby Boomers living in Chicago's North Shore who are looking to downsize and buy their home for life, *Enable* delivers an **EN**ergized (energy-efficient and a titive lifestyle) and Adapt**ABLE** (the house meets residents' changing needs) experience for its target users. *Enable* is more than a house. It's a home for today, and tomorrow.

INNOVATION

As a team, we approached innovation with a simple but critical framework: **Full innovation is the creation and capture of value.** Both *value creation* and *value capture* are important aspects of innovation, but many endeavors in academic and commercial settings focus only on the first. We believe that the constant pursuit of new inventions can lead to erroneous assumptions that if value is created, adoption will follow. A good idea or a novel invention, while creating value, does not automatically constitute innovation by our definition— capturing value and thus fully innovating will require a honest examination and holistic integration of our concept, approach, research, design, implementation, and execution. As such, from the start, we have closely integrated our team with our target customer demographic and practitioners of construction and energy technologies, as well as architecture and design. This is our framework to rapidly innovate: by taking a user-centric approach to marry the ingenuity and creativity of our student team members with the discipline and know-how of industrial leaders.

AGING-IN-PLACE & UNMET HOUSING NEEDS FOR BABY BOOMERS

Baby Boomers, born between 1946 and 1964, are important to the U.S. housing industry given their sheer numbers. From 2016 to 2060, the population of individuals 65 and older is projected to more than double — from 46 to more than 98 million — which represents an increase from 15 to nearly 24 percent of the total population.¹

In the city of Evanston, IL, home to Northwestern University and part of Chicago's North Shore, 20% of the population is projected to be 65 and older by 2020.² A community that takes pride in its age-friendliness, Evanston is one of 284 cities in the world and 45 cities in the United States approved to enter the World Health Organization (WHO) Network of Age-Friendly Cities.³ Being a part of this network requires that a city adapt its structure and services — including housing — “to be accessible to and inclusive of older people with varying needs and capacities.”⁴

Recent Boomer homebuyers aged between 52-61 project they will live in their homes for at least 20 years⁵ and approximately 90 percent of those over age 65 report wanting to stay in their homes as long as possible.⁶ This desire to **age-in-place** means that Boomers' houses will become important places for long-term care as residents deal with disabilities and other aging-related health challenges. However, the Joint Center for Housing Studies of Harvard University estimates that only 1 percent of the current housing stock contains the key features required to support aging-in-place, such as zero-step entrances, single-floor living, wide hallways and doorways, wheelchair-accessible light switches, and lever-style door handles and faucets.⁷

It is with this housing shortage and Evanston's interest in improving its current structures and services to create a culture of age-friendliness in mind that the Solar Decathlon team at Northwestern University set about designing a highly energy-efficient, yet fully-accessible home for a rapidly aging Baby Boomer demographic.



APPROACH & RESEARCH

A USER-CENTRIC DESIGN APPROACH

The House by Northwestern (HBN) team took a user-centric approach to the design of *Enable*. In other words, community members weighed in at every step of the design process about how *Enable* could best meet their needs. The buyer personas of “Michael and Lisa,” which are referenced frequently in our materials, encompass HBN market research data and represent that common voice of the active Baby Boomer living in Chicago’s North Shore.

Based on primary research from HBN User and Market Research Teams,⁸ our target market ranked the following housing features in order of importance to them: **comfort and livability, high-performance with functionality, easy home maintenance, sustainability,** and **affordability**. The crux of HBN’s design efforts was to create a home that balances the needs of the market with our team’s desire to create a sustainable, environmentally-friendly home. By packaging energy efficient and sustainable features into a comfortable, beautiful, accessible, and easy-to-maintain home, *Enable* offers sustainability without compromise.

RESEARCH PROCESS & DESIGN SOLUTIONS

Enable’s interior was designed with energy efficiency and the constraints and preferences of our users in mind. In order to understand what users value in a home and how their home influences their lifestyle, HBN’s User Research Team conducted a thorough user-research process that involved both qualitative interview and observation strategies, as well as quantitative data-coding methodology.

During fall of 2016, HBN collaborated with the Osher Lifelong Learning Institute (OLLI), which is a continuing education program that serves older adults in the greater Chicago area. Throughout 14 weekly sessions that were two-hours each, HBN team members co-lead discussions on topics related to our project, which included “What is the Solar Decathlon?,” “Sustainable Architecture” and “Interior Design.” Not only did the discussions reveal users’ attitudes towards sustainability, many of the ‘students’ participated in user interviews and observations, and even invited their friends to as well.

From the user interviews and observations, the team extracted “key insights”, one-line quotes that illustrated the relationship between user and home, and coded them in two different ways: themes and nouns. Themes were the intangible things users valued, like functionality. Nouns were the tangible things users valued, like their kitchens. As a result, the team produced a list of themes and nouns ranked in order of importance, as well as a set of recommendations to fulfill these values in the House. With these recommendations in mind, the House by Northwestern team prioritized the real-life values of our target demographic when designing *Enable*.

Following the fall class, many of the OLLI members chose to continue their involvement in the project. Between November and June, HBN members held 5 focus groups and 20+ shopping trips in order to expand the scope of their user research (Image 1). Since June, we also held 3 on-site reviews to solicit feedback from members as the house took shape. Throughout this duration of time, the originally-small group has expanded as OLLI participants introduced House by Northwestern to other prospective users.



Image 1. Two OLLI members on a shopping trip with our User Research Team.

In order to test these recommendations as they were being generated, HBN’s User Research Team conducted dimensioning sessions, created design matrices and drew storyboards. The dimensioning sessions gave HBN members

and users a sense of the space constraints in which they had to work, and allowed for easy testing of hypothetical furniture configurations. The design matrices provided a way to quantitatively compare solutions by of the number of requirements they fulfilled. Users prioritized some requirements more than others, and thus were weighted more heavily. The storyboards (or journey maps) visually described the course of a user’s experience with a product or a space. They allowed the team to identify micro-requirements, and depict how a brainstormed solution would fulfill those need .



IMPROVING UPON THE STATUS QUO

Observational research has shown that between 10 and 15 percent of all material brought to a conventional construction site ends up as waste, and nearly 40 percent of all residential and commercial waste in the United States is construction debris^{9,10}. Those staggering numbers motivated the HBN team to utilize a construction design and fabrication solution that addresses this major issue. It was clear to us that this status quo in construction left much value to be captured in terms of cost savings as well as waste diversion. By embracing software and digital manufacturing, *Enable* is also a prototype in which we wanted to change the narrative and public perception of “prefab houses.” With the aid of software and technology, prefab doesn’t have to be limited to fixed floor plans in a catalog like the Sears Roebuck homes of the early 20th century. Instead, prefab can be “hyper-customized” and

modularized to fit the needs and desires of each and every customer.

MODULAR INTERIOR WALL SYSTEM & OBJECT-ORIENTED PROGRAMMING

A unique aspect of *Enable* is the modular interior wall system where the basic building blocks are the same—the vertical posts, the way the frames of adjacent sections connect, the way panels are attached to the frame, etc. When all the parts are parametric, they can be standardized in the method they fit together but each part can be altered in size, material, or color, making them highly customizable and “future-proof.” With standardized connections and parts, new systems can be introduced with no compatibility issues: the same way that our parents’ LEGO bricks still work with ours today despite different themes. In addition, when new technologies are introduced (e.g. flat panel TVs in the last decade), the walls can adopt to accommodate them.

The majority of *Enable*’s interior walls is manufactured by the Canadian company DIRTT, an innovator in applying technology to construction. DIRTT’s connectors are extruded aluminum tracks designed to ensure close fit and strength but slide easily to allow for simple installation and removal. By using pre-engineered, pre-manufactured wall frames and panels, the interior space and rooms of *Enable* can be reconfigured to adjust and used over the owner’s different stages of life (including adding medical gases). Any required maintenance behind the walls will only require disassembly and not demolition.

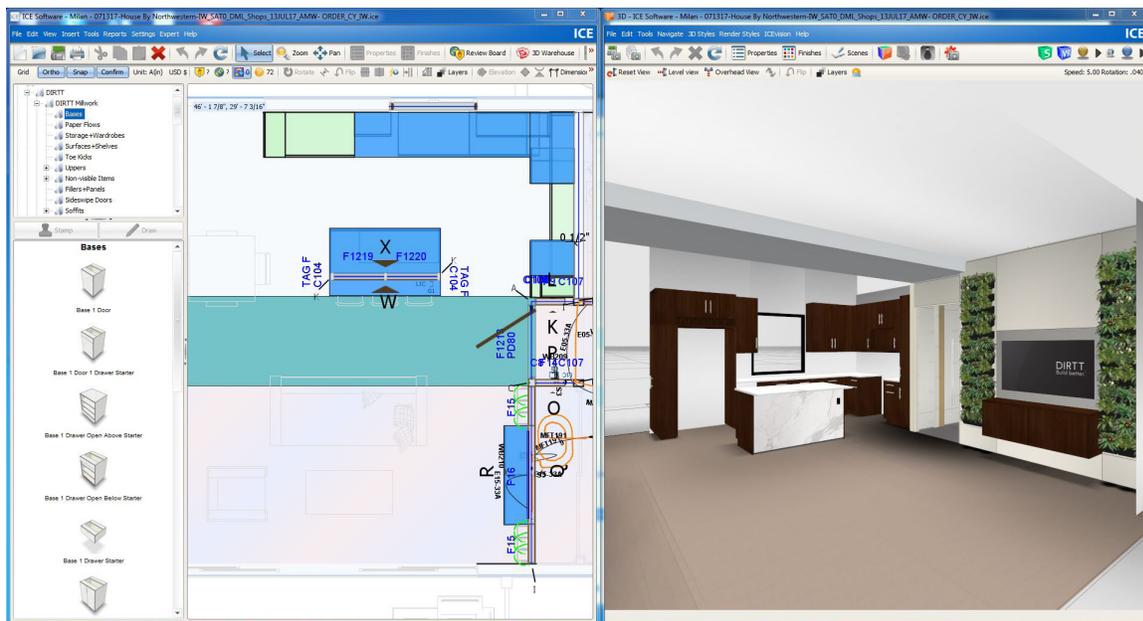


Image 2. Screenshot of DIRTT’s ICE design tool with real-time visualization

Style	Quantity	Price/Unit	Price
DIRTT S81 Thermal Antracite White	1	377.45	377.45
Face Mounted Tile Scrubed to Floor (2' - 4 1/8" X 1' - 1 15/16" - 2.72 sqft)	2	36.89	73.78
DIRTT S81 Thermal Antracite White	2	21.55	43.10
DIRTT S81 Thermal Antracite White	2	163.80	327.60
Sub-Total			821.93

Style	Quantity	Price/Unit	Price
DIRTT S81 Thermal Antracite White	1	442.43	442.43
Face Mounted Tile Scrubed to Floor (2' - 2 5/16" X 1' - 1 15/16" - 3.71 sqft)	1	50.06	50.06
DIRTT S81 Thermal Antracite White	1	48.21	48.21
DIRTT Wall Face Mounted Tile Option (3' - 2 5/16" X 6' - 3 7/8" - 4.22 sqft)	1	223.16	223.16
DIRTT Wall Face Mounted Tile Option (3' - 2 5/16" X 6' - 2 5/16" - 19.78 sqft)	1	35.03	35.03
DIRTT S81 Thermal Antracite White	1	33.75	33.75
Face Mounted Tile Scrubed to Floor (2' - 2 5/8" X 1' - 1 15/16" - 2.58 sqft)	1	156.41	156.41
DIRTT S81 Thermal Antracite White	1	11.89	11.89
DIRTT Wall Face Mounted Tile Option (2' - 2 5/8" X 1' - 3 7/8" - 2.94 sqft)	1	11.47	11.47
Face Mounted Tile Scrubed to Floor (8 11/16" X 1' - 1 15/16" - 0.84 sqft)	1	51.05	51.05
DIRTT S81 Thermal Antracite White	1	51.05	51.05
DIRTT Wall Face Mounted Tile Option (8 11/16" X 1' - 3 7/8" - 0.96 sqft)	1	51.05	51.05
DIRTT S81 Thermal Antracite White	1	51.05	51.05
DIRTT Wall Face Mounted Tile Option (8 11/16" X 6' - 2 5/16" - 4.47 sqft)	1	51.05	51.05
Sub-Total			1062.46

Image 3. Screenshot of DIRT's ICE design tool showing pieces inventory and project costs

The ability to bring this innovation to the residential built environment is afforded by object-oriented programming through DIRT's ICE® software platform. Object-oriented programming allows the designer to quickly apply a building part based solely on its function, with adaptable attributes. ICE can create interactive, real-time 3D experiences for the client and designer, and, by doing so, eliminate the need for wasteful mock-ups and shorten design times. Pre-engineering also reduces construction waste by not relying on the contractor to cut materials to size on site. ICE software delivers instant elevations and photo realistic renderings in moments, while simultaneously updating price, parts, and production information with every modification (Images 2 & 3). ICE then feeds production data directly to saws and CNC machines on the factory floors in their North American facilities. DIRT's presence in higher education and healthcare has been growing steadily, and we identified great

potential value to be captured by applying these tools and methods to the residential market.

ROOF-INTEGRATED SOLAR PANELS INSTALLED BY ROOFING CONTRACTORS

Enable utilizes a newly developed roof-integrated solar panel system as an alternative to rack-mounted ones. The result is an economical, low-profile solar system that's directly integrated into the house's roofing system for better aesthetics and longer performance value (Image 4, below, and Image A1, in Appendix). Since the solar panels are not elevated on racks above the house's shingles but surrounded with a perimeter protection system, the risk of animal infestation and leaks are greatly reduced. The roof-integrated design of the solar panels also removes the headaches for future re-roofing issues associated with traditional roofs and reduces long-term material waste as the solar panels are

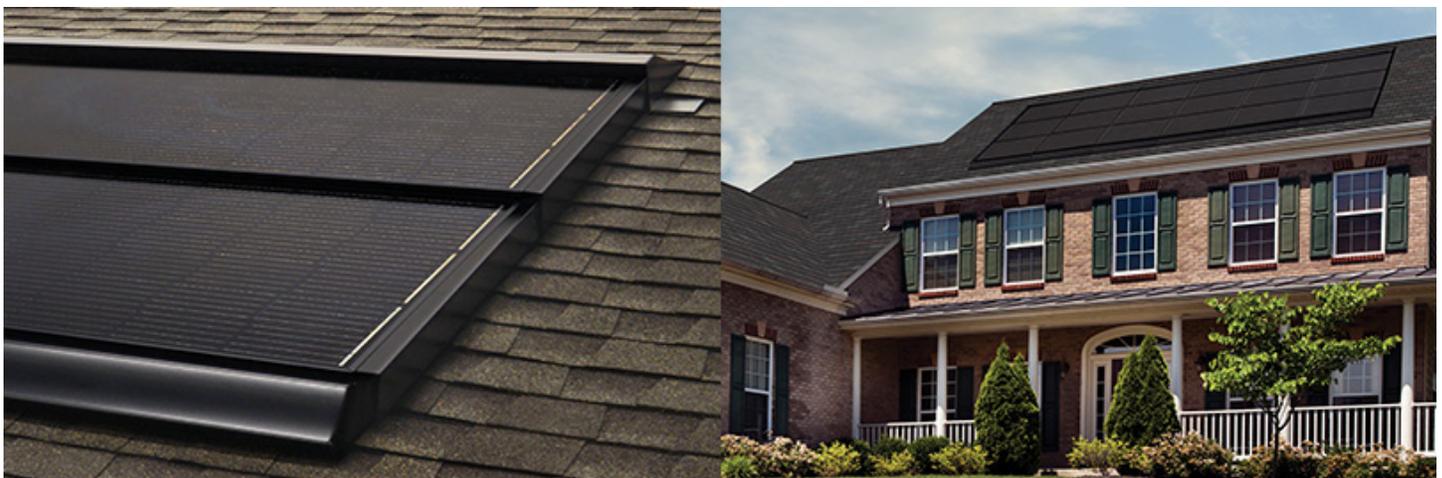


Image 4. Roof-integrated solar panels from GAF. Photo credit: GAF.

covered by a 25-year warranty that is significantly longer than shingles. By utilizing installation methods and parts standard to traditional residential roofs, as designed by GAF, the solar system can be installed by trained roofing contractors. Integrating solar installation with roof construction results in a more streamlined procedure that not only lower costs but also protects the integrity of the roof. Given that 79% of Americans in 2015 said the country should put more emphasis on solar in a Gallup poll¹¹, we believe that innovations in changing the installers and finance models of roof-top solar can speak to consumers more easily and thus capture more value and increase adoption in a rapidly growing market.

INNOVATIVE HEATING, VENTILATION, & AIR CONDITIONING

Enable's HVAC system is exactly sized to meet the thermal comfort and indoor air quality needs of our home's future occupants. The primary heating and cooling of the home is provided by a high-efficiency air-source heat pump, the Chiltrix CX34. This unit recently underwent AHRI certification and obtained a record-setting AHRI IPLV cooling efficiency rating of EER 23.02 (COP 6.75). By running our chiller at non-standard leaving-water temperatures (LWT), we can reach EER 30.72 (COP 9.0), all while maintaining thermal comfort of the home. This unit also utilizes a dynamic humidity controller (DHC), which modulates the LWT temperature based on the dew point of the indoor air to cool without dehumidification when it is not needed, or to significantly dehumidify the air if desired (Image 5). This allows for accurate control of interior humidity levels, as the DHC constantly checks the interior conditions against its setpoints. Details of this system can be found in the Engineering Narrative and its appendices.

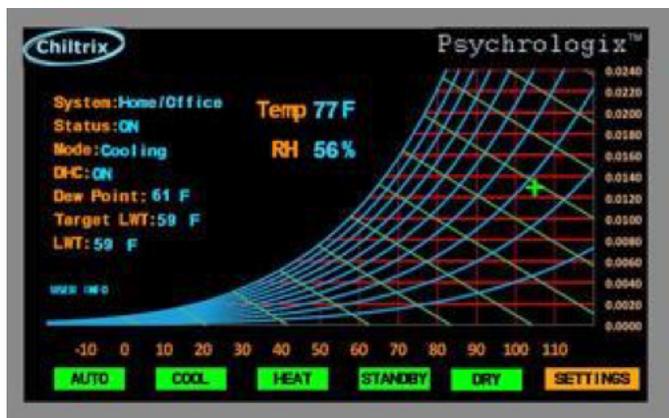


Image 5. Main Screen of Dynamic Humidity Controller. Source: Chiltrix
Our chiller also provides heat for our domestic hot water tank. Rather than requiring an additional heat pump for standard

heat pump water heaters, we can use the same outdoor unit for water heating. This unique approach requires fewer hardware components, and thus has smaller equipment costs. It also provides an efficiency benefit over traditional heat pump water heaters. Rather than cannibalizing heat from the air within the home to heat the water heater, our system pulls heat from the exterior to heat our domestic hot water. This reduces HVAC energy consumption significantly, while still retaining the efficiency benefits of heat pump water heating.

EFFICIENT ELECTRICAL DESIGN

The abovementioned solar array (6.5 kw) is DC-coupled to a 25 kWh AGM battery bank designed specifically for solar applications. The inclusion of battery storage enables us to increase our self-consumption fraction significantly over standard net-metered homes. Rather than selling solar energy back to the grid during the day, that excess energy is stored in the battery bank and used in the evening, allowing solar energy to power the home 24 hours a day.

The DC-coupled system configuration provides a resilient system which allows the solar panels to continue to power the home and charge the battery bank in the event of a power loss (Image 6).

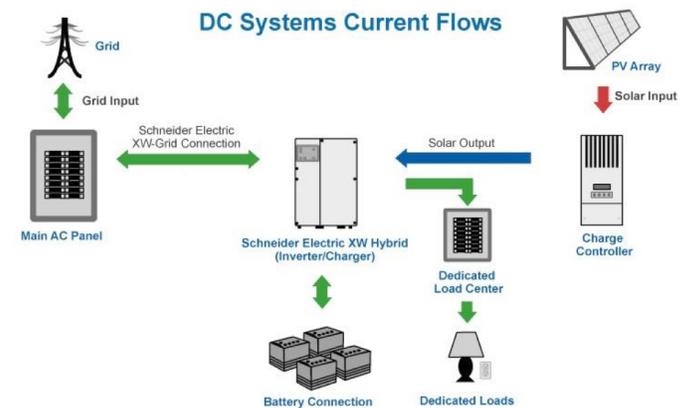


Image 6. Conceptual diagram of a DC-coupled system. Source: <http://www.amerescosolar.com/sites/default/files/dc-battery-backup-diagram.jpg>

All lighting, outlets, HVAC components, and appliances except for the range are backed up by this panel. Depending on energy consumption within the home and solar power production, Enable could operate off-grid indefinitely. This is a notable and unique benefit of our home, as AC-coupled or non-storage systems cannot use solar panels without a grid connection, thus requiring a fossil fuel generator if backup power is ever

needed. Based on feedback from our target demographic and potential buyer, these are significant features that made a positive contribution to the marketability of *Enable*.

IMPROVING HEALTH AND SAFETY, DURABILITY

Shown by EPA studies¹² over the years, Americans, on average, spend approximately 90 percent of their time indoors, where the concentrations of some pollutants are often 2 to 5 times higher than typical outdoor concentrations, and older adults, who are often most susceptible to the adverse effects of pollution, tend to spend even more time indoors. Serious health effects associated with indoor air pollution include respiratory and heart diseases, as well as cancer. *Enable* improves the health and safety of its occupants by several methods, two most noteworthy of which are 1) active ventilation, a mature technology that is now quite commonplace in Solar Decathlon houses, that allows for the filtration and dehumidification of the incoming air (reduces CO₂ levels, contaminants, allergens, and the likelihood of indoor mold growth), and 2) light-activated surfaces that self-clean and purify the air.

PHOTOCATALYTIC SURFACES THAT CLEAN THE AIR & THEMSELVES

Enable's exterior architectural surfaces and interior glazing of the south solarium are treated with a water-based (NSF and NIOSH approved), spray-applied coating that is photocatalytic (provided by PURETi). The invisible active material is titanium dioxide (TiO₂), a benign material used in everyday materials such as toothpaste and powdered sugar, and is activated by UV light from the sun. Titanium dioxide's ultraviolet photocatalytic property, known to chemists for nearly 50 years, is a renewable process by which solar energy initiates and accelerates the natural breakdown of volatile organic compounds (VOCs) and other detrimental organic materials. These types of surface treatment have been traditionally used in hospitals and food preparation facilities, but the HBN team is introducing it to the residential built environment where we discovered a huge consumer demand for wellness buildings and low maintenance surfaces.

When coated on interior surfaces, the TiO₂ coating is shown

to drastically decrease concentrations of formaldehyde, acetaldehyde, acetone, toluene, and heptane via the photocatalytic process (Figure 1).

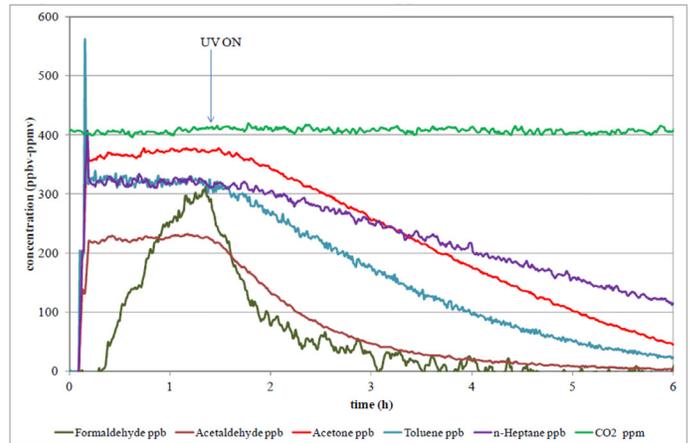


Figure 1. VOC evolution versus time at relevant concentrations in a controlled closed chamber. Source: CERTECH asbl (<http://www.certech.be/en/>)

When coated on exterior architectural surfaces, the TiO₂ is proven to not only reduce air pollution by reducing nitrogen oxides (NO_x) and sulphur oxides (SO_x), but it also helps keep the surfaces visibly cleaner (Image 7). As a result, significantly less maintenance is required than comparable houses, thereby reducing the chemicals and water used over the lifetime of the house. We expect this innovation to allow *Enable* to be more sustainable and more durable than a conventional house.



Image 7. Comparison of external architectural surfaces treated with photocatalytic coating after 3 years of no maintenance. Source: PURETi.

SIPS FOR BETTER PERFORMANCE & DURABILITY

Structural insulated panels (SIPs) are a building material consisting of an insulated foam core sandwiched between two structural sheathings forming a panel that is used as a wall of a house. SIPs are very well insulated and airtight, which allows a SIP house to consume less heating and cooling energy and to maintain better control over its indoor environmental conditions. SIPs are made in factories under controlled conditions and can be customized for any design thereby reducing construction waste. *Enable's* walls are composed of 6-3/8" SIP panels, with 5-1/2" of R-7 per inch closed-cell rigid polyurethane foam. The entire assembly of the walls provides an effective R-value of 40.5, with nearly no thermal bridges throughout the walls. Our SIP panels utilize one-piece corners, allowing the continuous insulation barrier to wrap around the corner rather than be stopped by framing members in the corners (Image 7). The roof is constructed with the same size SIP panels as the walls, with the addition of a 6" metal stud framing cavity with R-24 mineral wool insulation on the interior face. The roof has a continuous insulation barrier provided by our SIP panels, a feature often not found in conventional roof construction.



Image 7. *Enable's* SIP walls. Source: HBN team

SIPs don't just provide better insulation and improve *Enable's* energy performance, the rigid polyurethane form has been shown to be extremely durable, likely to endure well beyond the life cycle of any house. A study by Argonne National Laboratory showed that rigid urethane foam shows no compressive strength degradation after dry and wet aging,

as well as freeze-thaw cycling (think Chicago seasons). The study also showed that the same foam used in *Enable's* walls is resistant to microbial attack due to its chemical and physical structures¹³.

SUSTAINABILITY

Enable's user-centric approach allowed us to intimately integrate passive design strategies with state-of-the-art materials for the desired sustainability performances and user aesthetic preferences. The abovementioned DIRT modular interior wall system is one good example where sustainable design/manufacturing, materials selection, reusability, and life cycle came together in a single solution.

OLD WORLD FEEL MEETS 21ST CENTURY TECHNOLOGY

Through our user research, we learned that our target demographic ranks livability (and aesthetics) as their top priority and many desire to have a gourmet kitchen with stone countertops and finishes. To address this consumer demand while maximizing sustainability, *Enable* incorporated a "slab" of back-painted Corning Willow Glass in the kitchen island as a competition prototype demonstration. The end result is a finish that looks and feels exactly like stone, but is actually more durable and scratch resistant than the natural material. There are many advantages of using Willow Glass, same glass that is used for smart phone touchscreens: 1) conformable and easily applied to flat building materials, 2) scratch and stain resistant, 3) ultra-thin and can be rolled into long spools like paper, which results in less material scrap and far less energy and water spent on transportation and manufacturing. This demonstration is an example of the way modern technology has allowed Michael and Lisa to have the look they want without leaving a big carbon footprint.

PASSIVE STRATEGIES

Natural Lighting. *Enable* incorporates natural light in the interior of the home as much as possible. Being a Solar Decathlon, we chose to utilize the sun for more than just electrical power. Our Solatube skylight tubes, as well as our clerestory windows and large glass doors in the main living space, brighten up the interior and reduce the need for any

artificial lighting during the day.

Natural Ventilation. All exterior rooms in *Enable* have operable windows, allowing for natural ventilation when desired. Our operable high clerestories on the north, coupled with the sliding doors on the south face, allow for passive cross-ventilation, allowing warm air to rise up and out through the clerestories, drawing cool air in through the south doors. Additionally, our entry vestibule has a venting picture window to allow for passive regulation of the temperature in that space when needed.

Passive Thermal Buffer Spaces. Commercial buildings commonly have airlock spaces with multiple doors to gain entry, either through a vestibule or revolving door which meters the amount of conditioned air lost to the outside. This approach is rarely used in residential construction. *Enable*, however, uses this technique to reduce energy losses within the home while at the same time providing a sheltered passageway to the garage during inclement weather. The vestibule approach to the front door also creates an unconditioned space which can serve as a mud-room for dirty shoes or wet coats. While not actively heated, this space does benefit from a large glazing fraction on the south facade, allowing for large amounts of solar gain into the room. The insulated envelope in this room retains the heat for longer than an uninsulated room would, and serves as a sort of “double-wall” for the bordering walls touching the interior of the home. Simulations with DesignBuilder, predict this room will not to drop below freezing during a typical Chicago winter, and with standard winter solar gains could reach temperatures in the mid-50s during cold winter days. This is a significant gain from passive solar energy and makes the entryway a functional space year-round.



INNOVATION IN MARKETING

While innovation is mostly focused on product development, as discussed primarily in this narrative, the benefit of innovation in marketing by building on user-centric experiences and a longterm strategy can enable the product to better satisfy an existing market desire. *Enable*'s vision and marketing strategy is to promote sustainable living without compromise. We identified Baby Boomers as our target

clients not only because there are unmet housing needs in our city and around the country for this demographic, but also because it gave us an opportunity to change the narrative of sustainable living from “barebones” (e.g. turning thermostat down in cold winters) to “highly desirable, and high-performance.” This approach is not unique to HBN.



Image 8. Tesla's roadmap from Model S to the Powerwall to the Model 3.
Source: Tesla.

Tesla Motors in introducing the luxury sportscars the Roadster and Model S in 2012 opened the door to the “affordable” and wildly popular Model 3 today in 2017 (not to mention driving down lithium-ion battery costs for renewable energy storage in homes and at scale). Tesla founder Elon Musk blogged in 2006: “...the overarching purpose of Tesla Motors (and the reason I am funding the company) is to help expedite the move from a mine-and-burn hydrocarbon economy towards a solar electric economy... Critical to making that happen is an electric car without compromises, which is why the Tesla Roadster is designed to beat a gasoline sports car like a Porsche or Ferrari in a head to head showdown.” Musk goes on to say “The strategy of Tesla is to enter at the high end of the market, where customers are

prepared to pay a premium, and then drive down market as fast as possible to higher unit volume and lower prices with each successive model.”

It is a similar masterplan that HBN is pursuing: starting with a highly desirable product that is simply better (not cheaper) than the “conventional” alternatives through technology, design excellence, and customer value capture will lead to positive industry effects in technology and sociocultural perceptions. One example of HBN’s execution of our innovative marketing strategy is by associating residential energy-efficiency and smart home technologies with a luxury car brand. HBN has partnered with BMW for a regional sweepstakes (sponsored by BMW) in September 2017 to raise awareness of Solar Decathlon and high-performance homes in a different market segment. Rules for the sweepstakes are included in Appendix B.



CONCLUSION

Consistent with House by Northwestern’s innovation goal of creating and capturing value— ranging from the education of the student team members to the final product *Enable*— we have created a comprehensive, consistent, and integrated strategy to inform and educate a wide range of audiences about House by Northwestern and the Solar Decathlon. In our view, demonstration is only Step 1 of the process. In order to affect change and capture the immediate and long-term environmental, social, cultural, and commercial potentials of such an effort, we need to promote our key messages through in-person interactions, press relations, and social media. We have consistently strengthened relationships with community members and sponsors while seeking out new connections to bolster our support and network. Our diverse content, ranging from educational material to daily house updates, has allowed us to engage with local HBN stakeholders, who then distribute our messaging to followers across the globe.

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APPENDICES

APPENDIX A. RENDERINGS



Image A1. Overhead exterior view from the southeast, Summer



Image A2. Exterior view from the southeast, Winter



Image A3. Exterior view from the southeast.



Image A4. Exterior view from the southwest.



Image A5. Interior view from front door, looking into the living room, dining room, and kitchen.



Image A6. Interior view from door to the convertible room, looking into the living room and out to the sunroom.



Image A7. Interior view of the master bedroom; door to the right exits to the sunroom.

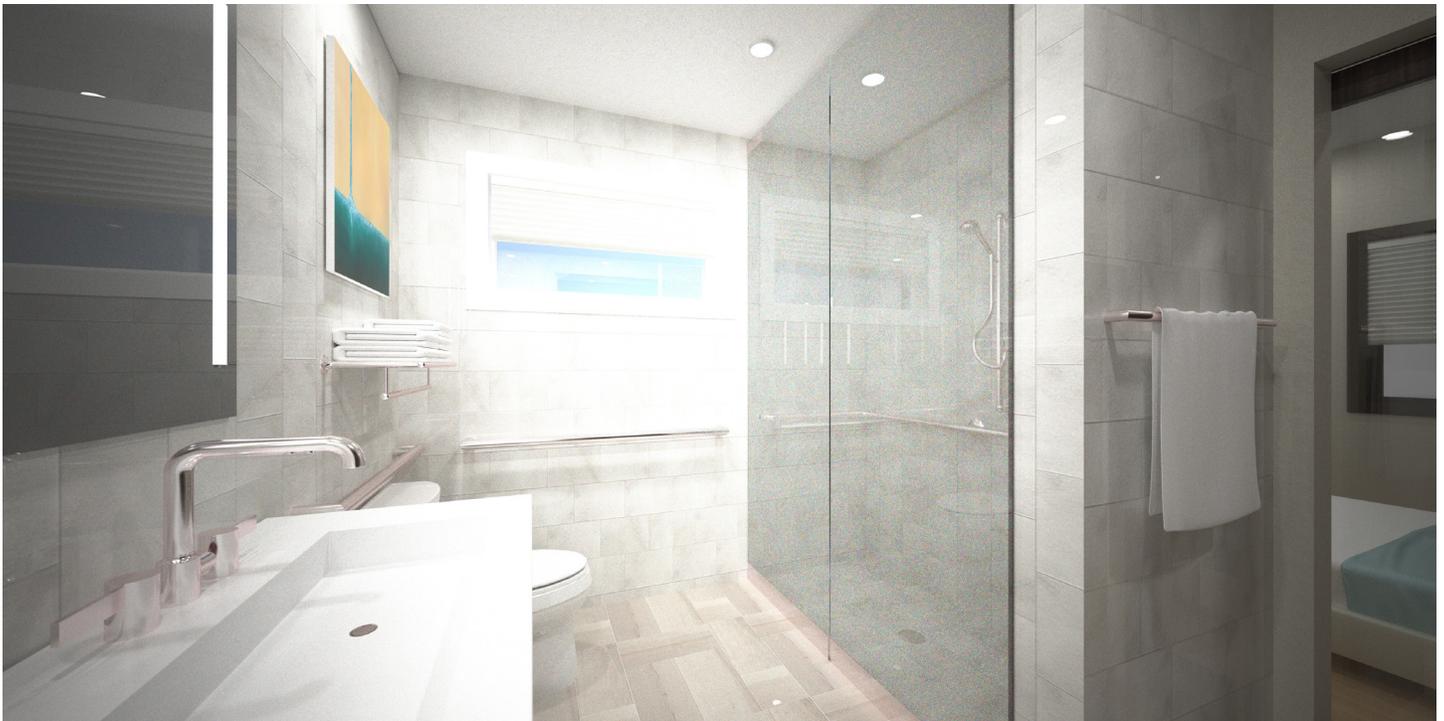


Image A8. Interior view of the master bathroom.

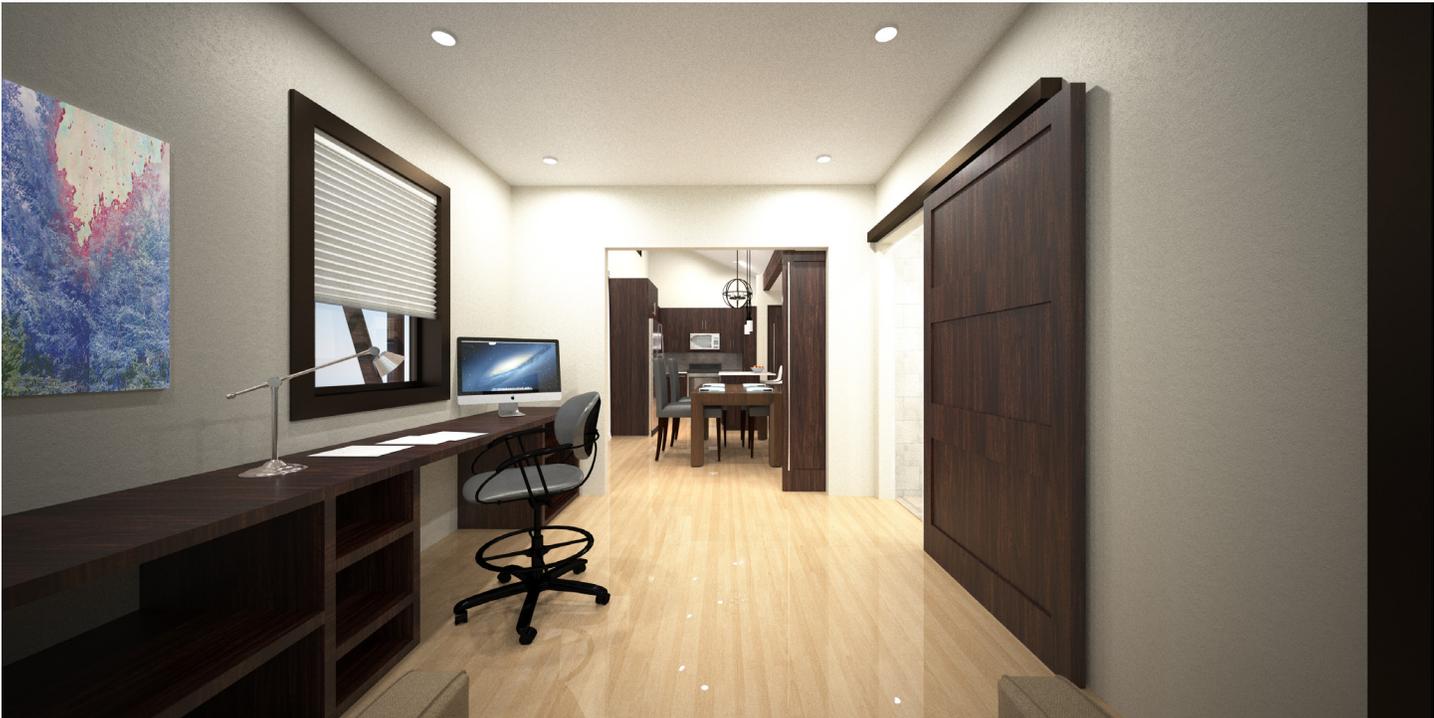


Image A9. Interior view of the convertible room, looking out to the dining room and kitchen.

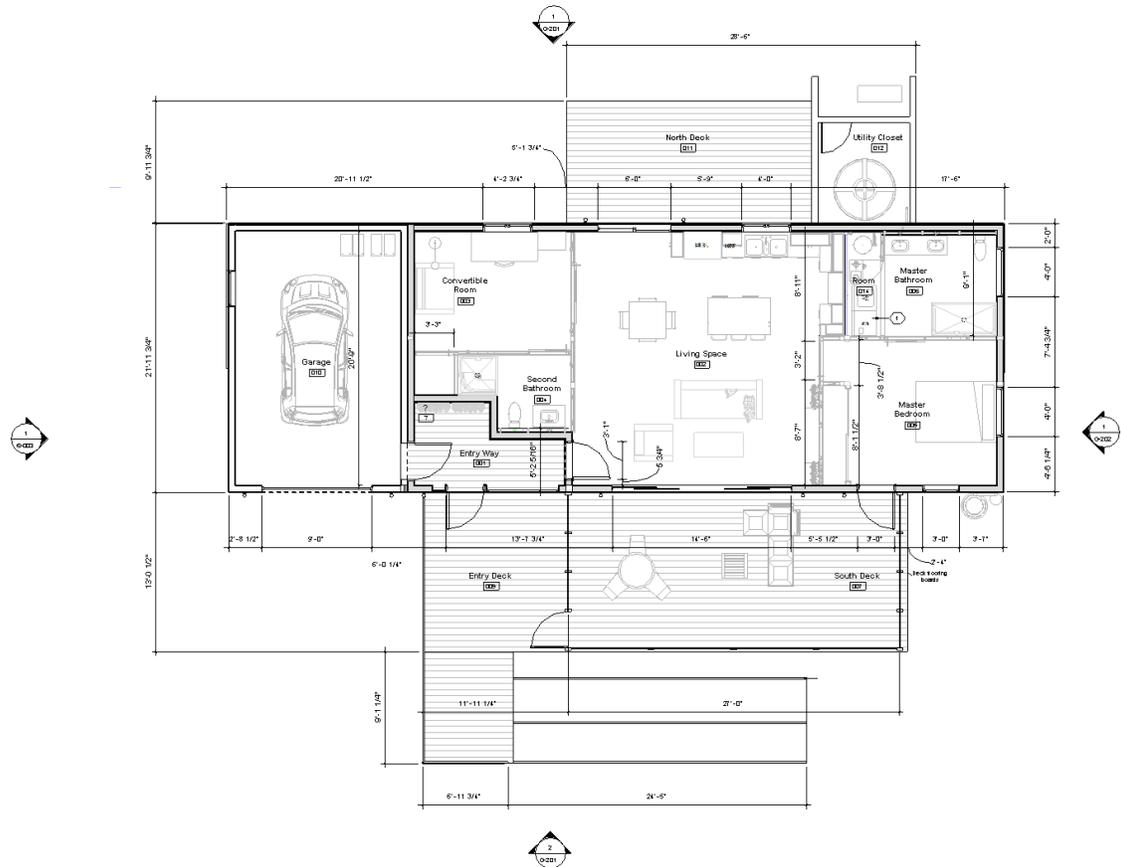


Image A10. Floor plan

APPENDIX B. BMW SWEEPSTAKES RULES

OFFICIAL RULES THE BMW ULTIMATE SMART HOME SWEEPSTAKES

NO PURCHASE NECESSARY TO ENTER OR WIN. A PURCHASE WILL NOT INCREASE YOUR CHANCES OF WINNING. OPEN ONLY TO **LEGAL US RESIDENTS**, WHO RESIDE WITHIN 100 MILES OF CHICAGO, IL AND WHO ARE AT LEAST 21 YEARS OF AGE BY SEPTEMBER 1, 2017. Employees (and their immediate families (parent, child, spouse or sibling and their respective spouses, regardless of where they reside) and those living in their same households, whether or not related) of the BMW of North America, LLC, The Central Region Advertising Council Inc. (“Sponsor”), BMW dealers located within the geographic parameters of Sponsor,, Octagon, Inc., Northwestern University and their respective parents, affiliates, subsidiaries and advertising and promotion agencies are not eligible to enter or win. By participating, entrants agree to be bound by these Official Rules and the decisions of the Sponsor, which are binding and final on matters relating to this promotion. Promotion is subject to all applicable federal, state and local laws.

SWEEPSTAKES PERIOD: The sweepstakes begins on at 12:00 a.m. Eastern Time (“ET”) on September 1st, 2017 and ends at 11:59 p.m. ET on September 30th, 2017(the “Sweepstakes Period”).

TO ENTER: During the Sweepstakes Period, visit www.bmwhousebynusweeps.com to complete and submit the online entry form. Limit one (1) entry per person for the duration of the Sweepstakes Period. Multiple entries received beyond the stated limitations will be void.

DRAWINGS:

Grand Prize Drawings: A grand prize drawing will be conducted on or around Wednesday, October 4th by Sponsor to determine the potential grand prize winner from among all eligible entries received for the duration of the promotion.

Potential winner will be notified by mail, phone, and/or e-mail and may be required to execute and return an affidavit of eligibility, a liability release and, where lawful, a publicity release within a specific time frame as determined in the sole discretion of the Sponsor. If such documents are not returned within the specified time period, prize notification is returned as undeliverable, potential winner is not reached on first attempt or potential winner is not in compliance with these rules, prize will be forfeited and, at Sponsor’s discretion, a runner-up may be notified. Sponsor reserves the right in its sole discretion to conduct a background check on potential winner and disqualify any individual who has been charged or convicted of a crime or, if Sponsor determines in its sole discretion that awarding a prize to such individual may reflect unfavorably on the Sweepstakes or Sponsor. Sponsors’ decisions are final and binding on all matters relating to this Sweepstakes. The odds of winning are contingent upon the number of entries.

PRIZES:

Grand Prizes: One (1) grand prize winner will be awarded a one-month extended test drive of a BMW i3, plus a Smart Home package, including: Lutron Caseta Wireless Smart Lighting Starter Kit (\$88), Nest Protect Smoke & Carbon Monoxide Alarm (\$119), Awair – Air Quality Monitor (\$199) and Amazon Echo Dot (\$49.99).

The Approximate Retail Value (“ARV”) of the Grand Prize is \$455.99. The total ARV of all prizes awarded is \$455.99.

Grand Prize dates and times are determined in the sole discretion of the Sponsor. Winner is solely responsible for all expenses, costs or fees associated with acceptance and/or use of the prize not specified herein as being awarded. Prize is awarded “as is” with no warranty or guarantee, either express or implied by Sponsor. Winner may not substitute, assign or transfer

prize or redeem prize for cash, but Sponsor reserves the right, at its sole discretion, to substitute prize (or portion thereof) with one of comparable or greater value. Winner is responsible for all applicable federal, state and local taxes, if any, as well as any other costs and expenses associated with prize acceptance and use not specified herein as being provided. All prize details are at Sponsor's sole discretion and subject to availability. The winner shall be required to provide a social security or tax identification number.

GENERAL CONDITIONS: Released Parties (as defined below) are not responsible for lost, late, incomplete, inaccurate, stolen, misdirected, undelivered, garbled, illegible or postage-due mail, entries or email; or for lost, interrupted or unavailable network, server, Internet Service Provider (ISP), website, or other connections, availability or accessibility or miscommunications or failed computer, satellite, telephone or cable transmissions, lines, or technical failure or jumbled, scrambled, delayed, or misdirected transmissions or computer hardware or software malfunctions, failures or difficulties, or other errors or difficulties of any kind whether human, mechanical, electronic, computer, network, typographical, printing or otherwise relating to or in connection with the promotion, including, without limitation, errors or difficulties which may occur in connection with the administration of the promotion, the processing of entries, the announcement of the prizes or in any promotion-related materials. Released Parties are also not responsible for any incorrect or inaccurate information, whether caused by site users, tampering, hacking, or by any equipment or programming associated with or utilized in the promotion. Released Parties are not responsible for injury or damage to participants' or to any other person's computer related to or resulting from participating in this promotion or downloading materials from or use of the web site. Persons who tamper with or abuse any aspect of the promotion or website or who are in violation of these Official Rules, as solely determined by Sponsor, will be disqualified and all associated entries will be void. Should any portion of the promotion be, in Sponsor's sole opinion, compromised by virus, worms, bugs, non-authorized human intervention or other causes which, in the sole opinion of the Sponsor, corrupt or impair the administration, security, fairness or proper play, or submission of entries, Sponsor reserves the right at its sole discretion to suspend, modify or terminate the promotion and, if terminated, at its discretion, select the potential winners from all eligible, non-suspect entries or from non-suspect entries who have provided Sponsor with the required tax identification information received prior to action taken or as otherwise deemed fair and appropriate by Sponsor. Entrants, by participating, agree that Sponsor, Octagon, Inc., Northwestern University and their respective parents, affiliates, subsidiaries and advertising and promotion agencies and all of their respective officers, directors, employees, representatives and agents (collectively, "Released Parties") will have no liability whatsoever for, and shall be held harmless by entrants against, any liability, for any injuries, losses or damages of any kind, including death, to persons, or property resulting in whole or in part, directly or indirectly, from acceptance, possession, misuse or use of any prize or participation in this promotion. Except where legally prohibited, entry into this Sweepstakes and/or winner's acceptance of prize constitutes permission for Sponsor and its designees to use his/her name, address (city and state), photograph, voice and/or other likeness and prize information for advertising, trade and promotional purposes without further compensation, in all media now known or hereafter discovered, worldwide in perpetuity, without notice or review or approval. In the event of a dispute regarding entries received from multiple users having the same e-mail account, the authorized subscriber of the e-mail account at the time of entry will be deemed to be the entrant and must comply with these rules. Authorized account subscriber is the natural person who is assigned the e-mail address by the Internet Service Provider (ISP), on-line service provider, or other organization responsible for assigning e-mail addresses.

WINNERS LIST: For the names of the winners, send a self-addressed stamped envelope to: The BMW Ultimate Smart Home Sweepstakes Winners List, c/o Octagon, Inc., 875 N. Michigan Ave, Suite 2700, Chicago, IL 60611 by November 30, 2017.

SPONSOR: The Central Region Advertising Council Inc., c/o BMW of North America 498 Commerce Dr, Schaumburg, IL 60173.

APPENDIX C. USER RESEARCH DATA

View the video we made about our user research process here: https://www.facebook.com/pg/HouseByNorthwestern/videos/?ref=page_internal

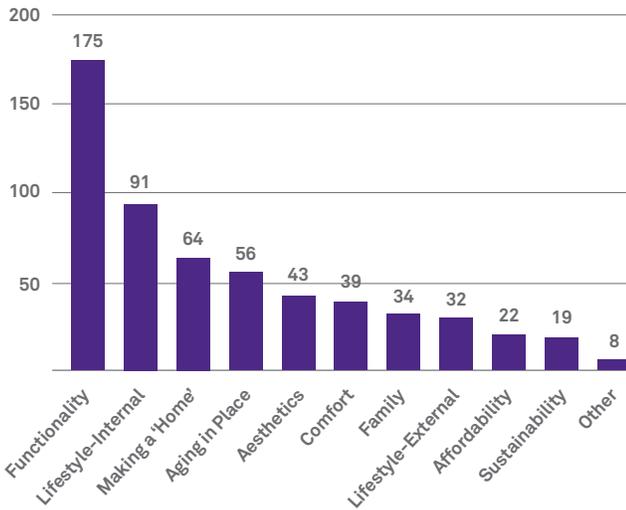


Figure B1. Target demographic housing priorities (ranked in order of importance). Source: House by Northwestern User Research Team ([bit.ly/2hgkw1k](https://www.facebook.com/pg/HouseByNorthwestern/videos/?ref=page_internal))

Requirements (Counter Stool)	Folio Top-Grain	Lowe Smoke C	Rouka Grey Up	Phoenix Ivory 2	Curran Crema Counter Stool
	\$499	\$279	\$349	\$149	\$369
Has a back for support, can grab on when getting in and out	1	1	1	1	1
Footrest to step on and off stool	1	1	1	1	1
No armrests so users can slide in and out	1	1	0	1	1
Feels sturdy, wide footprint by feet	1	1	1	1	1
Skinny enough to fit two in center island	1	1	1	1	1
User appeal (material, quality, design)	1	1	1	1	1
Comfortable to sit in (curve, upholstered)	1	1	1	2	1
Does not swivel	1	1	1	1	1
Design matches our aesthetic (grey=0.5, not grey = 1)	0.5	0.5	0.5	1	0.5
Price (ranked)	-1	2	1	3	0
TOTAL:	8.5	8.5	7.5	10	8.5

Requirements (Dining Chair)	Lowe Smoke Le	Curran Quilted	Sava Dining Ch	Monterey Charcoal Dining Chair
	\$199	\$349	\$249	\$199
Comfort	1	1	1	2
Customer reviews (durability, ease of cleaning)	-1	1	1	1
Aesthetic	1	1	1	2
Price	2	0	1	2
Lead time				
Seat depth no deeper than 17"	1	1		1
Width no larger than 19"	1	0		1
Seat height (29"-12") = 17"	0	0.5		1
TOTAL:	5	4.5	4	10

Figure B2. User Research Team design matrix used to determine most suitable counter stools and dining chairs. Requirements gathered from interviews, home observations, and focus groups with target demographic.

Requirements	Loveseat + swivel	2-seat sofa + armchair	Armless loveseat + swivel	L-shape	Right-arm + swivel
Can see 55" TV	2	-1		2	2
Looks out sunroom	-1	1		-1	-1
Comfortable armrests for lying down	1	1		-1	1
Easy to get in and out of	1	1		-1	-1
Correct firmness	1	1		1	1
Correct height	1	1		1	1
Sturdy	1	1		1	1
User appeal	1	1		0	1
ADA compliance + four route	1	1		1	-1
Total:	8	7		3	6

Armchair Requirements:	Elyse Swivel	Elyse Swivel Glider
Arms match sofa	1	1
Swivels to face conversation or outside	1	1
Does not rock to allow users to get up	1	0
Proper seat dimensions	1	1
Fits in space	1	1
Total:	5	4

Fabric Requirements:	Duet - Natural	Diamond - Flax
Interesting read	1	1
Nice hand	1	1
Matches color scheme	1	1
Easy to clean	1	1
Wrinkle resistant	0	1
Total:	4	6

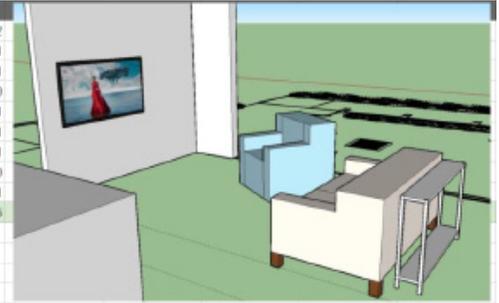


Figure B3. User Research Team design matrix used to determine most suitable living room layout. Requirements gathered from interviews, home observations, and focus groups with target demographic.