ARCHITECTURE

SPARC

U.S. Department of Energy
Solar Decathlon 2021

INTRODUCTION

Mountain towns are facing a serious affordable housing crisis. An increasing number of challenges are driving up housing costs and displacing both low- and middle-income residents.[1] These are teachers, restaurant staff, business owners, even seasonal resort employees, etc. Without housing for employees, businesses suffer. Service and seasonal workers are essential to the livelihood of the economies in mountain communities and they make up a critical portion of the population during the evolution of these towns.[2] Colorado is one of the fastest growing states in the US. Of the renters in Colorado, 50% are cost burdened, meaning they spend more than 30% of their household income on rent.

There is a serious local need for housing, specifically attainable housing that is not being met.

Property and construction costs are high, and developers are centered on building luxury homes with high return. These second-homes often sit unused for the vast majority of the year.[3] Furthermore, cold climates lead to short build seasons. Fraser, Colorado, for example, experiences an average of three months per year of effective construction time. Their

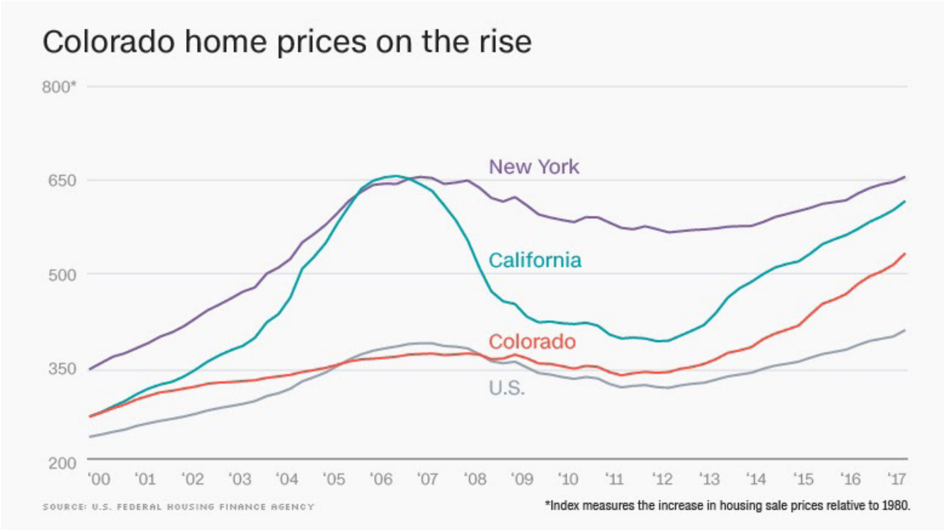

Figure 1: Colorado home prices compared to NY and CA

average temperatures during the hottest and coldest months are significantly lower than the national averages.[4] This, in addition to a universal skilled labor shortage, all contributes to what is now considered a crisis-level housing shortage in mountain communities. Something needs to change.

Underscoring all of this is the reality of climate change, a growing global issue, threatening the future of all people all over the world. The consequences of climate change are already here, which means there is no more time to waste with inaction on every level of society. Just months ago, Colorado experienced record-breaking wildfires that destroyed 700,000 acres of land in the state alone.[5]

The smoke that accompanies and extends far beyond these forest fires also expose people to poor health conditions and can cause respiratory issues later on. This kind of natural disaster will only become more normal and frequent in the West if people don't collectively decide to hold themselves accountable environmentally.[6]

With the SPARC House, the CU Boulder Team's goal was to confront these issues not only by designing a house whose form and functionality work hand-in-hand to provide innovative solutions but also by promoting a method of construction in which mountain towns can produce more housing options in a limited construction window of time.

The SPARC House was not designed in a mere hypothetical sense but rather for real people in a real mountain town with real issues. The design goals are globally-minded but the local context is real and it's relevant, so the team turned to Fraser. An old contender in the infamous rivalry over the trademark "Icebox of the Nation," Fraser, Colorado

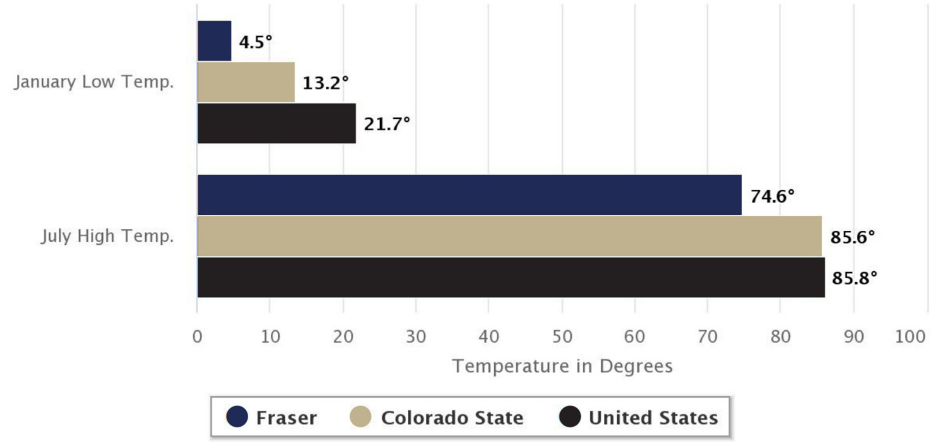

Figure 2: Fraser, Colorado, average annual low and high temperatures compared to Colorado State annd the US

is a charming town tucked away in the Rocky Mountains with a population of just 1,378 people.[7] Its close proximity to Winter Park (a mere six mile drive) makes Fraser a paradise for outdoor enthusiasts who appreciate the resort amenities without wanting to reside in the thick of it all. Fraser's residents relish in the quirky, small-town feel where everyone knows one another and shares a mutual love for both live music and eccentric public art. Over the years, Fraser has experienced the growing housing crisis firsthand. As accommodation costs rise, many are forced to relocate, which means businesses struggle to maintain employment. Those who can afford to live there are surrounded more and more by rentals that are occupied only a couple of months out of the year. Fraser is slowly losing its livelihood as a result of these issues. By bringing in a client from the beginning of the project, the CU Boulder Team was able to learn about the unique experiences of Fraser locals and how best to design to meet their needs and as the community likes to say, "Keep Fraser Funky."

The SPARC House was created on the basis of five main pillars of design:

Sustainability

The triple bottom line of sustainability was fundamental in the development of the design philosophy, and is thus the first pillar of design. The remaining four pillars are rooted in its foundation. The CU Boulder Team recognizes the importance of addressing all three principles of sustainability: economic prosperity, social equity, and environmental protection. The SPARC House strives to be effective on all three fronts.

Performance

High energy performance is critical to reducing the home's environmental impact and achieving the goal of attainable mountain living, which includes low operating costs for homeowners. Both passive and active design strategies have been integrated in the SPARC House in order to optimize energy performance, including strategic module placement and orientation for the site, a highly insulated structure, use of daylight and natural ventilation, passive preheat for ventilation, zone-based high efficiency HVAC equipment, and maximum power point tracking on the solar panels. The SPARC house aims to officially expel the old myth that all-electric housing is impossible in cold climates.

Attainability

To promote attainability, the SPARC House is designed to leverage prefabricated panelized construction methods and, with the addition of the rentable third module (ADU), bring in supplemental income to homeowners while offering more affordable rent options to service and seasonal workers than what is otherwise commonly available in mountain towns.

Resilience

The SPARC House will demonstrate the concept of resilience in several ways, including: grid islanding capability, battery storage, on-site energy generation, demand response capability, and a Building Automation System that can proactively control the space to an optimal electric demand profile. Climate change threatens grid reliability, with droughts reducing energy generation fromhydroelectric plants, high winds and wildfires that endanger power lines, and waves of extreme temperature swings that increase space conditioning loads to levels the current electric power grid cannot sustain. With demand response functions, the SPARC House can react to signals from the utility and reduce stress on the grid when requested.

Community

The SPARC House's addition of the accessory dwelling unit (ADU) provides a multifaceted sustainable solution to the displacement of lower-income seasonal and year-round service workers in mountain towns. Not only does it serve as a supplemental source of income for homeowners, but it also provides viable housing opportunities for these workers at lower costs than those otherwise commonly available. Including more rentable units in residential design strengthens communities by recognizing and meeting the needs of other members. At the same time, renting and leasing fosters interaction and communication within towns, promoting the development of new relationships and unified neighborhoods. Along with creating healthier economies and an increased sense of safety, integrated communities have the capacity to improve the overall well-being of their people as stated within the United Nations 17 Sustainable Development Goals. With the adoption of the SPARC House, mountain towns will be able to showcase the power of not just sustainable housing but also sustainable communities.

THREE MODULES & A SMALL FOOTPRINT

The SPARC House was designed to fit its three modules with two sitting directly adjacent to one another and one sitting vertically stacked above only one of the lower modules. Each of the three modules is 14 feet by 28 feet in footprint size, making them identical to each other and approximately 392 square feet each for a total of around 1,176 square feet. These two vertically stacked modules are referred to as the main unit. The bottom floor of the main unit houses the kitchen, living space, and powder room, while the office space, master bathroom, and master bedroom can all be found on the second floor along with laundry access.
With a small footprint and a second story, the SPARC House allows homebuyers to purchase smaller plots of land, an increasingly expensive resource in mountain communities. A myth about a lack of privacy when living small intimidates some, but the two floors allow for a clear separation of space and a distinction between shared space (downstairs) and private quarters (upstairs).

Other benefits of a small footprint and two story home include:

- A small footprint that lowers the cost of foundation and roofing.
- Great for 1st home buyers who may not need much space at first or are looking to slowly grow into their home
- Less time spent maintaining, more time spent on living


Figure 4: First floor plan with ADU (left) & Main Unit (Right)


Figure 5: Second floor plan showing Main Unit

- With innovative design tricks and interior decisions, small spaces don't have to feel small or cramped anymore
- More daylighting and passive solar heat in a smaller footprint
- Some roof is high enough to clear tree shadowing, meaning better solar access and higher PV production
- Views of mountain peaks

THE ADU (THE THIRD MODULE)

One of the most distinctive and innovative characteristics of the SPARC House is its addition of an attached accessory dwelling unit (ADU) with its own exterior entry and a lockoff access to the main unit. This adjacent module includes a studio layout with a sleeping area, bathroom, living area, and kitchenette. One of the options this feature grants homeowners is the ability to rent out the adjoining suite to seasonaland service workers. This not only provides the homeowners with an additional source of income but also provides more affordable housing options to other members of these mountain towns who are otherwise being displaced. The sharing of space and potential for interactions and new relationships enabled by including an ADU promotes stronger communities and the idea of solidarity as a whole, which stimulates the economy.

The ADU is designed and constructed as a completely separate module; the double wall serving as the demising wall reduces the sound transmission between units, enhancing privacy and allowing for a main house to be constructed and an ADU added at a later date. At the discretion of the homeowners, the ADU also allows for potential future expansion of their space. Innovative home designs not only meet the current needs of the homeowner but also look toward future needs with consideration and intention. The ADU is an adaptable space that can be repurposed into a second bedroom, larger living space, etc. sparing the homeowners from requiring costly expansions to grow their home.

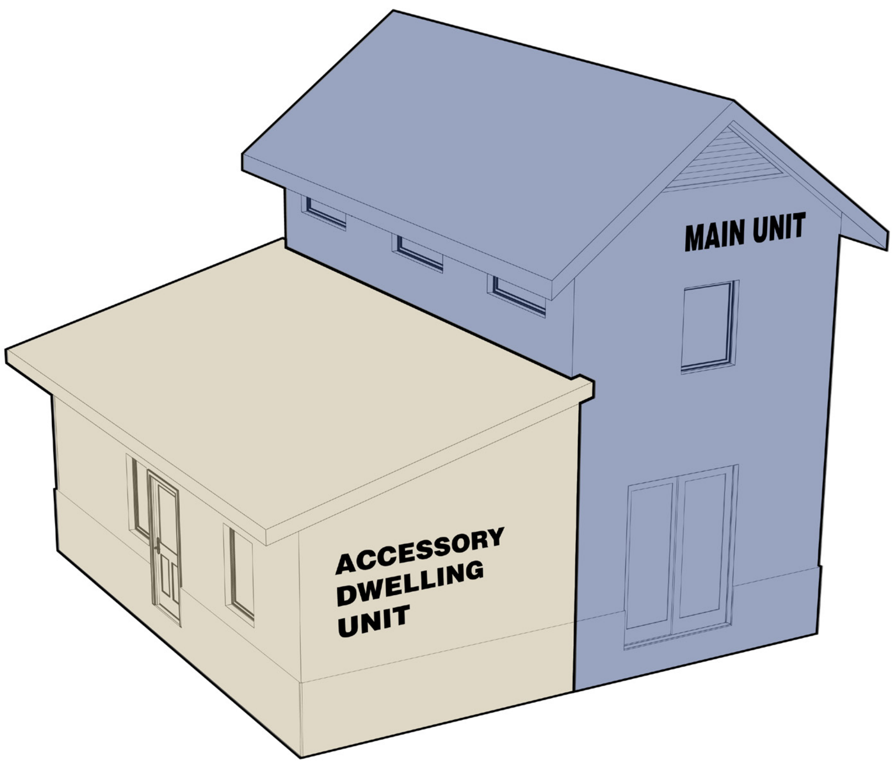

Figure 6: Volumetric division of ADU and Main Unit

PREFAB PANELIZED

The SPARC House's construction method proposes a smart solution to the cold climate and short build season associated with mountain towns. Instead of traditional stick-built construction, each wall panel was first assembled in Simple Homes' prefabrication facility in Denver, Colorado. The CU Boulder Team's close partner and mentor throughout the competition, Simple Homes has utilized a Scandinavian-inspired panelized

Figure 7: On site panel assembly in Fraser

building system to streamline the construction process in a high-quality and sustainable way. Building the panels within an enclosed facility allows the team to work during colder months without being affected by the harsh weather, meaning that timeline is more stable and reliable. The use of precision-focused technology and material optimization methods means that the prefabrication process also results in the reduction of waste produced during framing by around 15%. After the completion of each individual panel within the factory, they were then transported via truck to the final site in Fraser where they were all crane-assembled in less than one day. With the assembly of panels being expedited, the process of achieving a weather-tight exterior allows for a 75-90% reduction in framing time and more flexibility in the construction schedule.

EXTERIOR

The SPARC House has four facades that each play an important role in its energy performance as well as its curbside appeal. The east, south, and west facades all include exterior access, windows, and ventilation, optimizing daylight-use and circulation of both people and outside-air. The north facade includes only two windows in order to allow cross-ventilation and north-facing views but to minimize thermal losses as the north facade poses the greatest risk to the thermal integrity of the house. The majority of the north wall being uninterrupted means that homeowners have the ability to uniquely characterize their home, whether that be with an exterior climbing wall, a painted mural, landscaping, etc. A dark pine tar coating was applied to the siding in order to create both a modern mountain cabin aesthetic and to serve as an additional passive energy measure by absorbing sunlight and therefore retaining heat more than a lighter stain would. Pine tar also carries its own important history, as it was the earliest known standard of wood preservative applied on skis to keep them from absorbing water.[8]

A corrugated metal wainscot was chosen to sit at the base of the house to protect the walls from water and ice damage caused by snow build up on the ground. A dark metal blends easily with the shiplap siding and creates a more cohesive look.
Where the pine tar siding meets the roof overhang, a contrasting light wood soffit made from beetle kill pine presents a continuation of the interior wood ceilings with an added warmer stain. Beetle kill pine is a locally available material that is used from dead or dying trees, without sacrificing the integrity or strength of the wood. Both the lower and upper roof is protected by black standing seam metal in order to absorb heat more effectively to melt snow. The upper roof's gable form is an intentional design decision to add a sense of balance to an otherwise off-centered form.

MATERIALS

The material selections were made with insulation, environmental impact, and indoor environmental


Figure 8: Pine tar's historical use on skis


Figure 9: Exterior perspective showing pine tar siding and light wood soffit

were used sparingly, only to seal and insulate critical areas such as at module joints and along roof-wall connections to ensure longevity of the insulation value near the eaves. The wall panels and roof sections are composed of materials that have both a low global warming potential and low/no-VOCs.

The 14-¾” inch thick exterior wall of the SPARC House features advanced layering of sustainable and energy efficient materials in order to create the most optimal and protected interior environment.

In order from the exterior to the interior, the SPARC House wall includes:

Pine Tarred Shiplap Siding

Furring (1x4)

Mineral Board Insulation (Rockwool Comfortboard 80)

Weather Resistive Barrier (Solitex Mento)

Plywood

Wood Framing (2x8)

Batt Insulation (Havelock sheep wool)

Vapor Barrier (Intello Plus air barrier and vapor control)

Furring for Interior Electrical Chase (2x2) and/or Additional Sheep Wool Insulation

Drywall (Covered Immediately with Zero-VOC Paint)

Indoor finishes include beetle kill pine ceilings and hickory hardwood flooring, a product which achieves GREENGUARD Indoor Air Quality Certification. Interior detailing maintains a light interior finish, uses mirrors to enhance the effect of the available daylight, uses diffuse wall sconces to keep electric lighting on surfaces near the occupants, and uses live-edge wood countertops and an Aeroponic kit for both functionality and outdoor connection year round.

PASSIVE AND ACTIVE SYSTEM INTEGRATION

Both passive and active design strategies were incorporated in the SPARC House in order to provide optimal comfort for its residents in a mountain town’s cold climate.

Passive

The goals of the passive design were to allow the use of daylight and natural ventilation in all zones, minimize heat loss, prevent moisture build up within the envelope, and still allow for passive cooling in the hottest months of the year. Heat loss is targeted by achieving a high R-value in the exterior envelope. The combination of mineral and havelock wool together perform at an insulation value of R-42walls/R-59 roof. Current code for climate zone 7 requires R-20+5 continuous for walls and R-49 with 38 acceptable at truss heel. Havelock wool also presents the added benefits of preventing harmful chemicals from circulating in the air, managing moisture well, and absorbing sound, which is important for smaller homes with

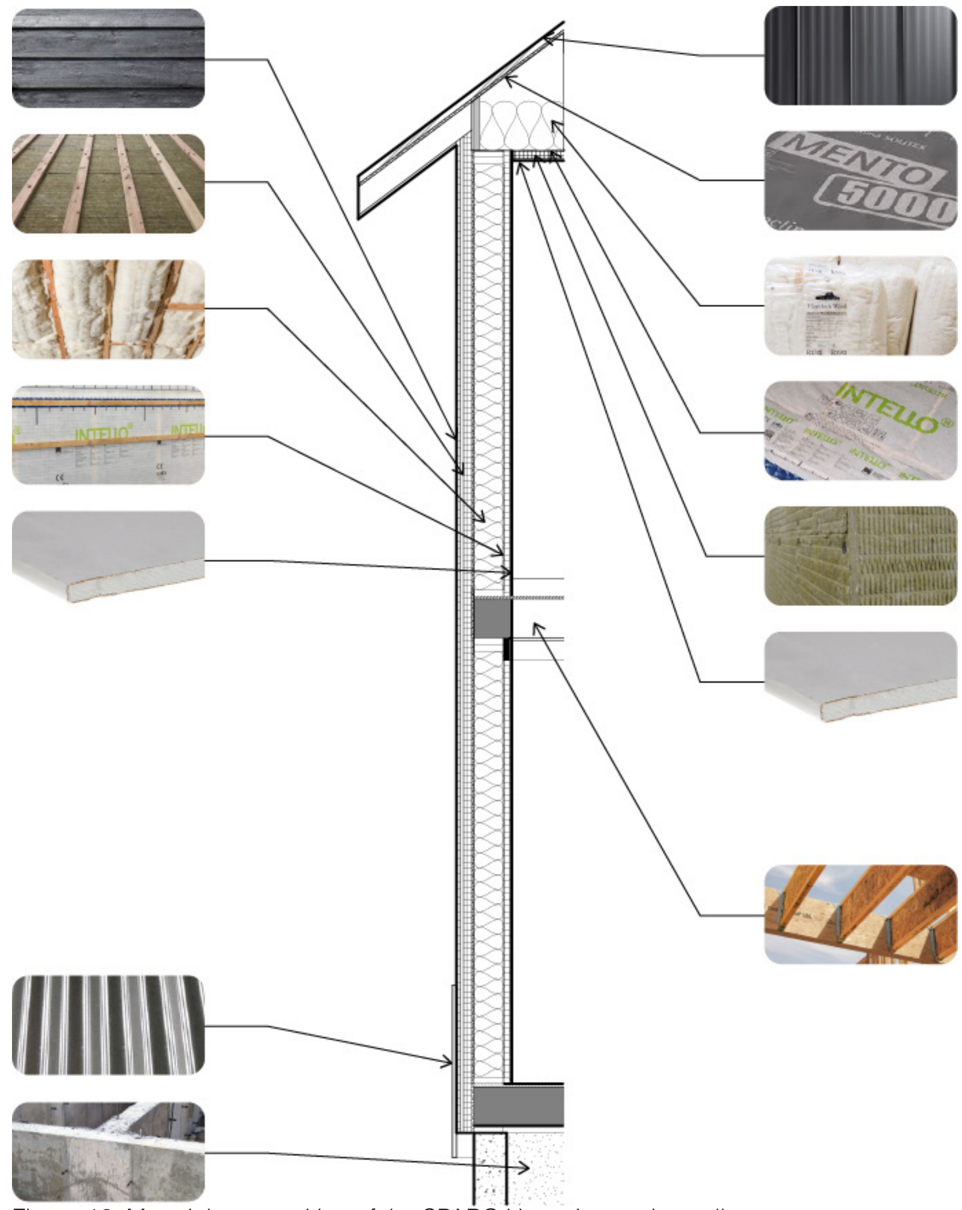

Figure 12: Material composition of the SPARC House’s exterior wall

an attached ADU. Spray foam insulation was largely avoided due to its high Global Warming Potential (GWP).

The southeast orientation of the house was another intentional measure used to increase heat gain from solar radiance and maximize solar power generation, while still complying with the constricted property lines. Strategically placed windows allow for daylight and views in every room. In the summer months, operable windows on all sides allow for cross ventilation as needed.

Active

The SPARC House's active energy systems work hand in hand with its architecture to create an optimal living experience.

Three single-zone heat pumps allow each of the three modules to be thermally controlled separately. This enables the ADU's heating set point to be reduced whenever it's not in use, allowing homeowners to save both energy and money. The outdoor units are placed intentionally to receive as much sunlight as possible, which improves performance, and to limit length of refrigeration lines. This heating system functions alongside an Energy Recovery Ventilation (ERV) system in order to retain heat and preserve humidity in the air, an important factor for indoor comfort in dry mountain climates.

Home Assistant (HASSIO) is an open source integration tool that the SPARC House employs as a home automation system. It allows for control of smart home technology from one interface without requiring an annual subscription or fees and is dedicated to protecting user privacy. HASSIO offers a collaborative community of people developing code for the integration of home appliances and systems that can be leveraged by the homeowners over time. With endless opportunities for customization, HASSIO is a scalable tool that can be used both by noviceand experienced programmers to learn more about their home's energy usage and how to optimize their own unique smart home experience.
The southeast-facing half of the gable upper roof of the house holds 8 photovoltaic panels while the lower southeast-facing shed roof holds 16 panels. The gable roof's pitch is 9:12 to encourage snow shed and maintain PV production. The lower shed roof (over the ADU) is intentionally angled with a pitch of 3:12 to allow space for windows on the upper main module that can provide cross ventilation without compromising ceiling height in the ADU. The vertical dimension in a small space holds considerable impact in maintaining a feeling of openness without requiring substantial floor space. Even while providing an internal feeling of spaciousness, the lower roof can still be reached with a snow rake for snow removal as needed.

LIGHTING

The hardwired electric lighting scheme consists of an ambient layer of warm but efficacious light at the living and working areas of the house. Recessed downlights in the lower main area and ADU are used to provide ambient lighting for movement through the space, and near the main kitchen and ADU kitchenette. Additional under cabinet lighting at the kitchens will reduce shadows on working surfaces. The downlights are used in the areas where recessing the luminaries will not penetrate an air barrier. A soffit is used in the ADU for this purpose. Sconces with diffuse, luminous surfaces and distribution onto nearby walls provides surface lighting near living spaces for the dual purpose of functional lighting and to suggest warmth near the seating areas. A sconce mounting was used specifically to enable mounting in the wall's electrical chase versus in the ceiling, which would require

Figure 13: Exterior showing window placement, PV, & 2 of 3 exterior heat pump units

penetration and sealing of the continuous air barrier. Throughout the house, light colored surfaces and mirrors will compliment the surface illumination to create a sense of spaciousness in the small footprint. Each unique luminaire type in the house, in each zone, is its own lighting zone so that each space can have a range of lighting scenes, each contributing to a unique function and feel of the zone as needed at a specific time. This will help the small footprint meet a range of space needs. The lighting control intent is manual-on with automatic-off at regularly scheduled times of day through the energy information system. The off times will coincide with high daylight hours and midnight to offer a reset to all-off in the house.

DESIGN DETAILS

Various details incorporated in the SPARC House's design add an additional level of innovation and attention in its architecture. A murphy door, for example, separates the main unit from the ADU. Serving as a discreet entryway by doubling as a bookcase, a murphy door allows both of the bottom modules to feel complete and closed off when used separately.

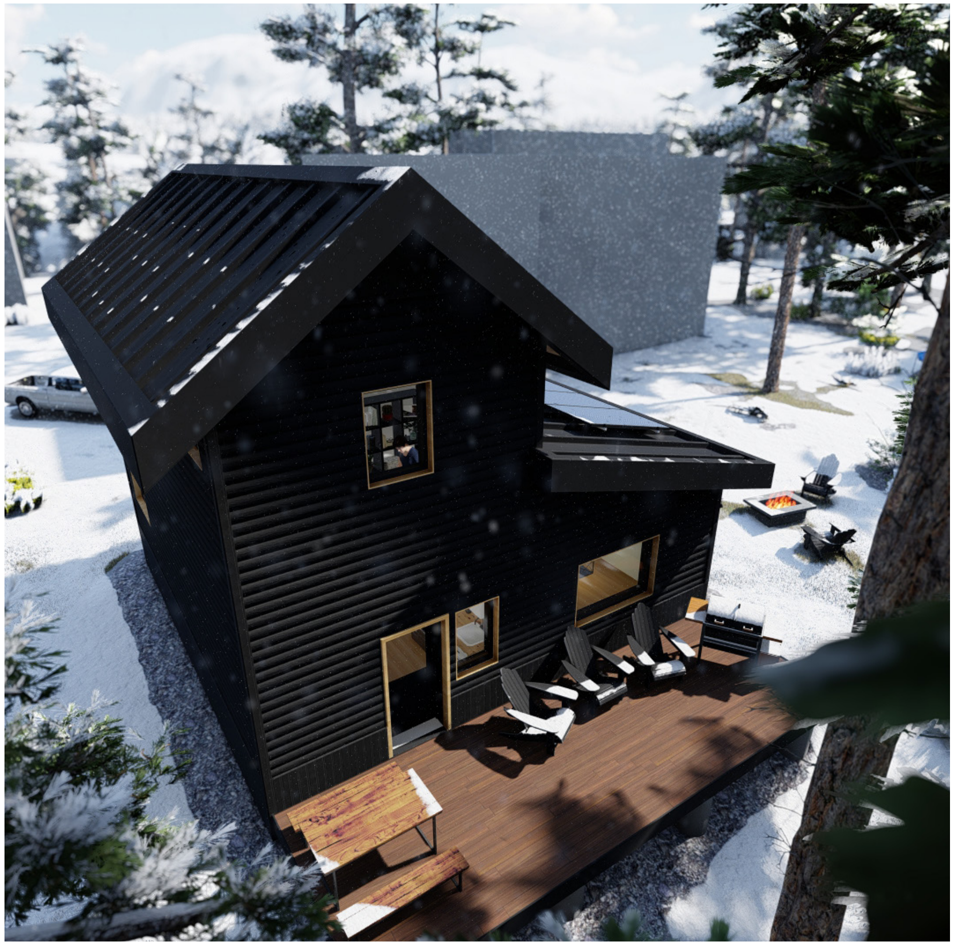

Figure 14: Interior perspective of Main Unit showing location of lockoff to ADU

The staircase in the main unit ascends above both a half-bathroom and an exposed nook, allowing the homeowners to use the area for storage of any kind. It is important that space is not wasted, especially in houses with a small footprint. Both the murphy door, and the under-stair nook serve as evidence that elements of a home can be both intentional and multifunctional.

Windows are an important feature in any home, but they are particularly important in the SPARC House, in which their size and position is pivotal to daylight, passive heating, and making the most of 360 degree scenic views. On the upper floor, various high-set windows allow

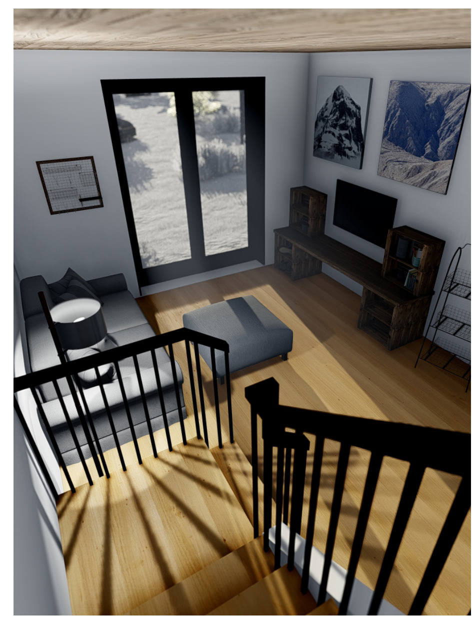

Figure 11: Interior perspective

the homeowners to appreciate the mountains without sacrificing privacy. High-set windows also allow for more passive heating during the winter months when the sun is lower and more rays are not obstructed by the roof overhang. In the summer, these operable windows can be opened to enable cross ventilation throughout the upper module.

Throughout the SPARC House, the windows are set flush with the exterior of the walls in order to protect from wind and snow. This simultaneously creates a shelf-like space on the indoor sill, which can hold plants or photographs at the preference of the owners and essentially extends the feel of indoor space.

Endnotes

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