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Title

Healthier Homes: Integrating Emerging Design Strategies into Affordable Housing

By

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MASTER OF ARCHITECTURE

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HEALTHIER HOMES: INTEGRATING EMERGING DESIGN STRATEGIES INTO AFFORDABLE HOUSING

A Thesis
Submitted to the Graduate Faculty
of the
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By

Rachel Marie Schall

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1. INTRODUCTION

The materials used in a home can have a significant impact on a person's health. At least half of a person's life is spent inside their house, thus the detail choices of that space should be carefully considered. Specifying Alternatively better building products "would reduce residents' exposure to a host of health issues in the built environment by decreasing or eliminating the use of toxic chemicals in building products" (Malloy & Gonzalez, n.d.). Using healthier building products benefits the user as well as the natural environment. This is especially important to study in the design of affordable housing. Many users of affordable housing belong to vulnerable groups such as children, people with disabilities, and the elderly. It is crucial that healthy and sustainable housing design is offered to people of all income levels.

Housing affordability is an issue that plagues the United States today. The median sales price of housing has increased from $322,600 to $416,100 in the last three years – a 29% increase (U.S. Census Bureau & U.S. Department of Housing and Urban Development, 1963). To help combat this, the creation of affordable housing or low-income communities has become more common. However, many "Low-income communities continue to grapple with poor housing quality, high energy costs, and disproportionate health burdens stemming from fossil fuel pollution in their homes and communities" (Mills, 2021). Low-income households should have the ability to experience a home built with little to no toxic materials and enjoy the health benefits of living in a green home.

Integrating sustainable design into affordable housing must become a more customary practice, as it is the architect's responsibility to protect the health, safety, and welfare of the public regardless of socioeconomic status. Why aren't these strategies more commonly integrated to benefit the population? Duluth, MN has already begun addressing the issue of housing affordability and sustainable design. The Green New Deal Housing group in Superior, WI has begun constructing net-zero single-family homes aimed at low-income households, but

the rate of these homes' development is slow. This paper will address ways to efficiently construct affordable and sustainable residential units in Duluth, MN.

1.1. Research Objective

This research focuses on healthy building materials and sustainable practices and how to integrate those practices into an affordable housing development in Duluth, MN. I will be investigating new sustainable materials to potentially be integrated as well as different approaches to integrating the materials. The objective of this thesis will be to design a two-family dwelling that integrates the sustainable practices and healthy materials researched. The dwellings are to be used in the creation of an affordable housing development in Duluth, Minnesota. I would like my research to be used as a reference for future affordable housing developments in Duluth and surrounding areas.

2. BACKGROUND

This section will address the affordable housing issue in Duluth, MN, as well as the several types of healthy building materials, construction methods, and sustainable options available to use. The research gathered from these topics will help inform my decisions which will lead to a completed design.

2.1. Duluth, MN

Duluth, MN is home to 87,000 residents. The average household size is 2.23 people and the median age of a person living in Duluth is 33.9 ("Duluth Housing Indicator Report," 2022). Almost 40% of the households in Duluth rent, and 60% own a home ("Duluth Housing Indicator Report", 2022). The town sits 155 miles north of Minneapolis, MN, and rests next to Lake Superior. The "city is built into a steep, rocky cliffside" (*Lake Superior Streams - City Facts*, n.d.). According to the International Energy Conservation Code (IECC), Duluth is in climate zone seven.

2.1.1. Housing/Renting Affordability in Duluth

The price of housing continues to increase rapidly in the United States and in Duluth, MN. In the last five years, the median sale price of housing has increased from $185,000 to $260,000 ("Duluth Housing Indicator Report", 2022). Renting has also increased significantly in the last few years.

In a report from 2018, "fifty-four percent of Duluth renters [had] reported being cost burdened" ("Duluth Housing Indicator Report", 2018). In another report from 2022, the average home price had increased from $175,807 to $260,000 from 2017 to 2022 while the median household income had only increased from $49,078 to $58,014 ("Duluth Housing Indicator Report", 2022). "A household should pay no more than 30% of its gross income on housing" ("Duluth Housing Indicator Report", 2018). "A household in Duluth would need to make $52,442 annually to afford a $174,807 home – the 2018 average home value of an owner-occupied single-family home in Duluth (Housing Market Analysis. Duluth). In 2020 the average

rent was $1,125 per month (“Duluth Housing Indicator Report”, 2021), and in 2022 the average rent was $1,329 per month (“Duluth Housing Indicator Report”, 2022). This means renters are paying on average $1,600 more per year than they were two years ago.

2.1.2. Current Housing Stock

In addition to the drastic increase in housing prices, Duluth also has many homes that are old or in poor condition. “Over 65% of homes in Duluth are over 50 years old (Housing Market Analysis. Duluth)”and, “the average lifespan of a house, according to HUD, is 40 to 50 years, without significant annual maintenance” (Housing Market Analysis. Duluth). “Of Duluth’s housing stock, 90% was built before lead-based paint was removed from the market” (Housing Market Analysis. Duluth). “Of the 26,068 homes with lead-based paint, approximately 10,427 are occupied by low- to moderate-income households, including 3,645 households at or below poverty level” (Housing Market Analysis. Duluth).

Figure 1. Current House for Sale in Duluth, MN

2.1.3. Homelessness in Duluth

There is an issue of homeless youth in Duluth that is related to physical and mental health disabilities, low monthly income, relationships with parents, issues acquiring public assistance, and a shortage of transitional housing (van Wormer, 2003). According to the Duluth Housing Indicator Report, in 2022 there were 139 households in emergency housing, 125 in transitional housing, and 183 homeless households ("Duluth Housing Indicator Report", 2022). "The mean average age of applicants [for transitional housing] was 18.1 years old" (van Wormer, 2003) and the ages ranged from 15 to 21 (van Wormer, 2003). Most applicants were female and white. "A partnership between the government and state to provide adequate housing and programming for homeless youth" should be investigated (van Wormer, 2003).

Figure 2. Homelessness
Note: Anderson, P. (2020, November 5). Homeless in Duluth.
ttps://duluthreader.com/articles/2020/11/04/116201-homeless-in-duluth

2.2. Prefabricated Construction

"Prefab construction is when buildings, or sections of a building, are manufactured in advance and can be easily shipped or assembled" (*Prefab Vs. Modular Construction*, n.d.). Prefabricated construction "takes place in a factory setting where many of the inconveniences of on-site construction such as weather delays and safety hazards are eliminated" (*Prefab Vs. Modular Construction*, n.d.). "Financial savings, reduced time of construction, and safer conditions outline the benefits... of prefabricated construction methods" (*Prefab Vs. Modular Construction*, n.d.).

There are different variations of prefabricated construction such as modular construction and panelized construction. All techniques "can be used with several materials such as timber, steel, and concrete" (*Prefab Vs. Modular Construction*, n.d.).

2.2.1. Modular Construction

Modular construction is a form of prefabricated construction where the structure is "constructed off-site, under controlled plant conditions, using the same materials and designing to the same codes and standards as conventionally built facilities – but in about half the time" ("What Is Modular Construction?," n.d.). "Prefab is any construction process that does not take place on-site, while modular construction consists of repeated sections called modules being built in the factory and then assembled on site" (*Prefab Vs. Modular Construction*, n.d.). Modular construction requires a lot of careful planning because making changes can be difficult when the construction process begins. Building typologies that modular construction is used most in are healthcare buildings, educational institutions, offices, and shelters for industrial, forestry and oil workers, and residential construction (*Prefab Vs. Modular Construction*, n.d.).

The benefits of modular construction include greater flexibility and reuse, less material waste, improved air quality reduced construction schedule, elimination of weather delays, built to code with quality materials, safer construction, and better engineered building & BIM. ("What Is Modular Construction?," n.d.).

Modular buildings are systemized, but they “may still have access to a high level of customization” (Innella et al., 2019). Reducing the complexity and customization of the modules is essential to increase the productivity of construction.

2.2.2. Panelized Construction

Panelized construction is another method of prefabricated construction “in which certain framing components are built off site and then transported to the site for assembly. This technique has been reported to make homebuilding more efficient and affordable” (Ghosh et al., 2021). This form of prefabrication is used mostly “for home building as it allows for more customization than modular construction while still being faster and more efficient than standard on site home building” (*Prefab Vs. Modular Construction*, n.d.).

2.3. Thermal Mass

Thermal mass is defined as “the ability of a material to absorb, store and release heat” (*Thermal Mass | YourHome*, n.d.). Thermal mass is a form of passive cooling design which allows the absorption of heat during the day and release of heat during the night, allowing for the reabsorption of more heat the following day. This passive cooling strategy can be used within walls, roofs, or flooring.

“Thermal mass should be placed where it will best be able to absorb heat in the colder months and be shaded in the warmer months” (Employment, n.d.). Therefore, thermal mass should be placed near windows where it can be exposed to direct sunlight in the winter.

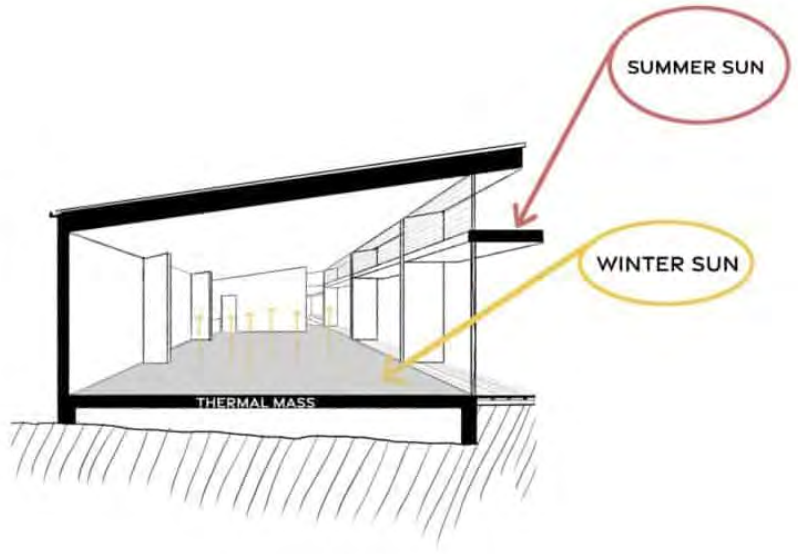

Figure 3. Thermal Mass Passive Cooling
Note: *7 Stunning Ways To Add Thermal Mass To Your Eco Home*. (2021, August 26). https://ecoshack.com/thermal-mass/

A thermal mass floor usually consists of "a concrete slab, insulated underneath and around the edges" (Employment, n.d.). The concrete slab can form the whole floor, or a small strip can be exposed along the sunny side of the room (Employment, n.d.). A rule used for thermal mass is that "the surface of the concrete should be left thermally exposed, e.g., by using finishes such as paint, tiles, or plaster. The presence of internal finishes such as plasterboard and carpet will, to some extent, act as an insulating layer and reduce available thermal mass" (*Concretes Thermal Mass Benefits for Housing*, n.d.).

A concrete slab-on-grade thermal mass floor "should be insulated both underneath and around the edges" (Employment, n.d.). This is done in severe cold climates to prevent heat loss. "To maximize the heat exchange to and from the slab, the surface receiving sunlight should not be carpeted" (*Concretes Thermal Mass Benefits for Housing*, n.d.). "Slab-on-ground floors with under-floor insulation work well with under-floor heating, which is ideally suited to high thermal mass dwellings" (*Concretes Thermal Mass Benefits for Housing*, n.d.).

2.4. Slab-On-Grade Foundations

A slab-on-grade foundation is a practice in which “the concrete slab that will serve as the foundation for a building or other structure is formed from a mold that is set into the ground. The concrete is then poured directly into the mold, leaving no space between the ground and the structure” (*What Is a Slab-On Grade Foundation?*, n.d.). The concrete is “poured over a layer of an approved vapor barrier material that usually has been placed on a base of gravel to allow better drainage” (*The Benefit of a Slab on Grade Foundation Design*, n.d.). “Slab foundations provide good insulation since the thick layer of concrete helps prevent heat gain or loss” (Epp, 2023). There are two types of slab foundations: monolithic and stem wall.

Benefits of this “technique are that it is quite sturdy while also being relatively inexpensive” (*What Is a Slab-On Grade Foundation?*, n.d.). It is also “less vulnerable to infestation from termites and other pests because there is no hollow space between the ground and the bottom of the structure” (*What Is a Slab-On Grade Foundation?*, n.d.). Slab-on-grade also lessens the environmental impact of construction in two ways: “first it significantly reduces the amount of CO2 produced during the production and delivery of materials, and second, it provides a wall that is substantially more insulated for every dollar spent” (*The Benefit of a Slab on Grade Foundation Design*, n.d.).

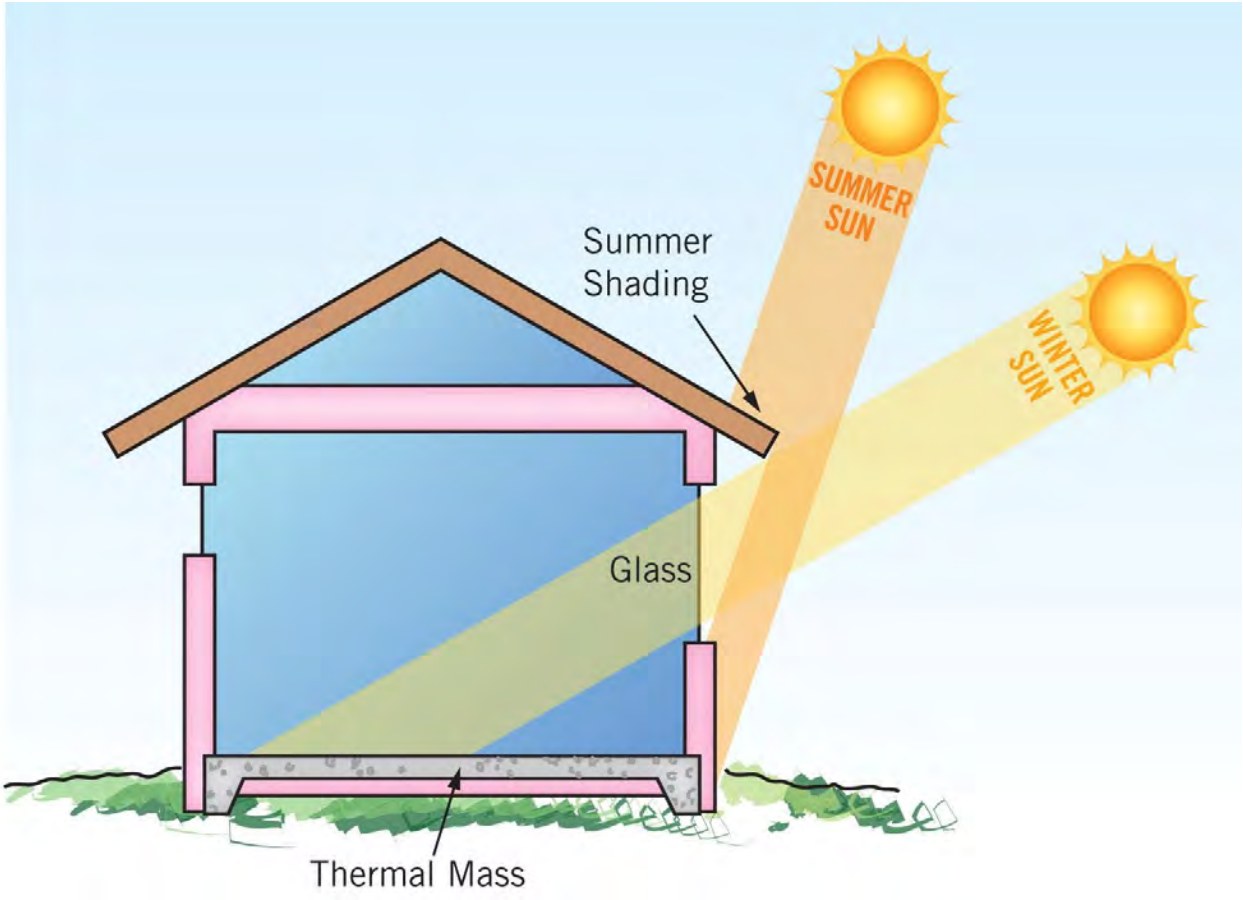

Figure 4. Example of Thermal Mass Slab-on-Grade Foundation
Note: *The Benefit of a Slab on Grade Foundation Design*. (n.d.). DesignwithFrank. Retrieved March 6, 2024, from https://designwithfrank.com/blogs/building-guide/slab-on-grade-foundation-design

Negatives of this foundation system include "lack of access from below for the installation of utility lines, a low elevation that exposes the structure to flood damage, and the potential for heat loss in cases where the ground temperature drops significantly lower than the interior temperature" (*What Is a Slab-On Grade Foundation?*, n.d.).

2.4.1. Monolithic Slab Foundations

A monolithic slab is formed if the concrete for a slab-on-grade foundation is all poured at once (*The Benefit of a Slab on Grade Foundation Design*, n.d.). Since the concrete is all poured at once, "construction is faster and labor expenses are lower" (*What Is Slab-on-Grade Foundation?*, n.d.). "The slab generally rests on a bed of gravel for drainage and is reinforced

with a fiber mesh throughout, to strengthen the foundation and protect from other elements" (*Monolithic Slab vs. Traditional Foundations*, 2021).

"The cost of a monolithic concrete slab is $5 per square foot" (Cusick, 2023). Monolithic slabs are durable, low-maintenance, and energy efficient (Cusick, 2023). However, there is no access to place plumbing and electrical after installation, expensive repairs, and lower resale value of the house (Cusick, 2023).

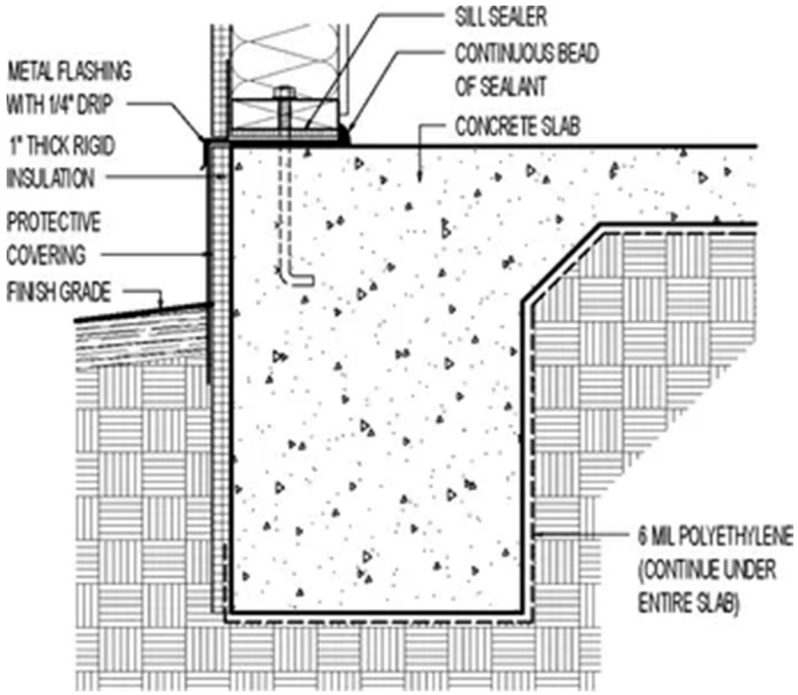

Figure 5. Monolithic Slab-on-Grade Foundation Detail
Note: *Monolithic Slab w/ 1-in. Rigid Foam—GreenBuildingAdvisor*. (n.d.). Retrieved March 6, 2024, from https://www.greenbuildingadvisor.com/cad/detail/monolithic-slab-w-1-in-rigid-foam

2.5. Fastfoot Formwork Membranes

Fastfoot Membranes is a type of formwork technique that uses high density polyethylene fabric. It "is a green replacement to lumber and plywood for forming concrete footings" (*Fastfoot Concrete Footing Residential*, n.d.). "A 100' foot roll of Fastfoot forms the same concrete as 1,500 pounds of lumber" (*Fastfoot Concrete Footing Residential*, n.d.).

Figure 6. Fastfoot Footing Membrane
Note: *Fastfoot Concrete Footing Residential*. (n.d.). Retrieved March 24, 2024, from https://www.fab-form.com/fastfoot/fastfootOverview.php

Advantages of Fastfoot are that it is significantly less expensive than lumber to form concrete footings, adapts to uneven ground, prevents rising damp, prevents ground water contamination, and is greener (*Fastfoot Concrete Footing Residential*, n.d.). “Rising damp is the wicking of water through the footing, into the concrete wall, and its evaporation inside the building. Rising damp increases the moisture load which leads to dampness and mold” (*Fastfoot Concrete Footing Residential*, n.d.). “Rising damp is prevented by isolating the concrete footing from ground moisture” (*Fastfoot Concrete Footing Residential*, n.d.).

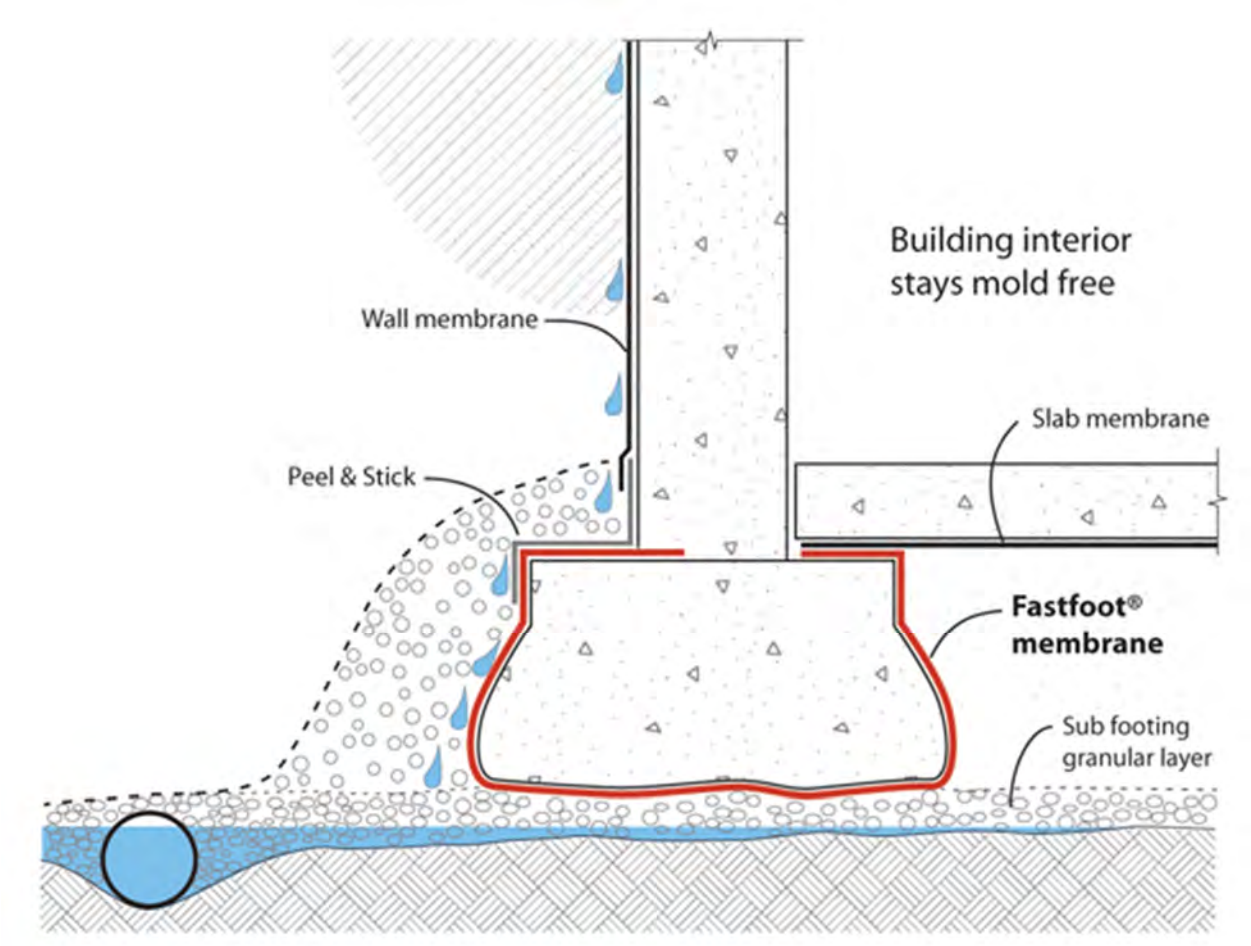

Figure 7. Preventing Rising Damp Using Fastfoot formwork
Note: *Fastfoot Concrete Footing Residential.* (n.d.). Retrieved March 24, 2024, from https://www.fab-form.com/fastfoot/fastfootOverview.php

2.6. Interior Wall Finishes

There are several types of interior wall finishes that each have positives and negatives. This section goes through multiple types of wall finishes and discusses the positives and negatives of each.

2.6.1. Drywall

Drywall, also known as gypsum wallboard, "is a panel of gypsum plaster pressed between two sheets of heavy paper. It is a lightweight and easy-to-install material used in modern construction" (*Drywall vs Sheetrock vs Plaster - MI Remodelers*, n.d.). Drywall is an inexpensive material. Drywall does not allow air to flow through it if installed correctly.

2.6.2. Plaster

Plaster is often a more “labor-intensive” material choice, and “requires a more specialized technique” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.). There are different varieties of plaster such as lime plaster, venetian plaster, and gypsum plaster. They each vary in style, durability, cost, and application skill.

2.6.2.1. Lime Plaster

Lime plaster is “lightweight, flexible, and crack resistant” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.). It is breathable but does not work well in extremely damp environments (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.). It also “requires a talented, experienced plaster specialist” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.). Lime plaster varies around $9 to $11 per square foot, this includes labor (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.).

2.6.2.2. Venetian Plaster

“Venetian plaster is made with fired lime plaster. It was used in the ‘90s during the Tuscan movement” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.). There are no aggregates mixed in with this plaster. “It is durable, low maintenance,” and “applying it is a complicated procedure that must be performed by someone who knows what they are doing” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.). “The Venetian plaster price per foot is $5 to $15” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.).

2.6.2.3. Gypsum Plaster

Gypsum plaster is “easy to install, does not require an extra finish, and provides good thermal insulation” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.). However, “it doesn’t recover well from water damage, is less robust mechanically, and may be prone to rust due to steel corrosion” (*Fixr.Com | Cost of Plasterer | Plastering Prices*, n.d.).

2.7. Insulation

There are several types of insulation to consider when insulating a building. The insulation types discussed in this section include hempcrete, structurally insulated panels, fiberglass batting, rigid foam, and spray foam.

2.7.1. Hemp + Lime Construction

"Hemp is an agricultural plant that does not need insecticides or pesticides to flourish" (Malloy & Gonzalez, n.d.). There are many uses for hemp such as "food, paper, canvas, textiles, and construction materials" (Malloy & Gonzalez, n.d.). "Hemp photosynthesizes carbon dioxide more efficiently than trees do. One ton of hemp absorbs 1.63 tons of CO2. Though one tree can absorb up to forty-eight tons of CO2, it takes decades to grow and requires a lot more acreage than hemp does" (Malloy & Gonzalez, n.d.). It takes one hundred days for hemp to reach maturity, survive in various conditions, and it can be harvested twice a year (doubling its carbon sequestration rate) (Malloy & Gonzalez, n.d.).

Hemp lime construction or hempcrete is a sustainable building material/method that is slowly being used more in the United States. Hempcrete is created when hemp, water, and lime are mixed. Lime acts as the binder in the hempcrete mixture. Hempcrete is "a building material that continues to sequester CO2 throughout its entire life cycle" (Malloy & Gonzalez, n.d.). It "is a better alternative to other traditional wall systems, having good insulation and fire-resistant properties and a low carbon footprint" (Malloy & Gonzalez, n.d.). "Hempcrete is one of the most fireproof building materials. In 2020, an ASTM E-84 test was conducted on hempcrete, which measures the flame speed of fire on the material being tested. Hempcrete scored a 0 to 450 scale, which is the best possible rating when it comes to how fireproof a material is" (*Building A Hempcrete Home: Say Goodbye To Classic Concrete - The Tiny Life*, n.d.). In the last 30 years, hempcrete has been growing in popularity in Europe and in the US. In 2019, "the city of Austin, Texas, built a community of hempcrete tiny houses" (*The House That Hemp Built*, 2022), and in 2022 a house in Fargo was constructed using hemp lime construction.

Fargo's hemp house uses 12" thick walls containing a hemp lime mixture packed between plywood forms. The hempcrete mixture is left for six to eight weeks to cure and then finished with a lime-based plaster. Fargo's hemp house study suggested that heating and cooling costs could be 40 to 50 percent lower than in conventional structures (*The House That Hemp Built*, 2022).

Figure 8. Fargo's Hemp House.
Note: The house that hemp built: Fargo developers build hempcrete home to study energy-saving benefits. (2022, August 3). InForum. https://www.inforum.com/business/the-house-that-hemp-built-fargo-developers-build-hempcrete-home-to-study-energy-saving-benefits

Hempcrete has a tremendous ability to absorb carbon – "one acre of hemp captures and stores about 11,000 pounds of carbon dioxide during its growth cycle" (*The House That Hemp Built*, 2022). Hempcrete can be used as an alternative to concrete and insulation, it is recyclable, lightweight, and has a low thermal conductivity (Barbhuiya & Bhusan Das, 2022). "Additionally, Hempcrete can be reused at the end of its life and broken down and recast as new hempcrete" (Malloy & Gonzalez, n.d.). "Hempcrete material alone usually costs about $0.70-$0.85 per

pound, or $5.25-$6.75 per cubic foot of material after installation" (*Building A Hempcrete Home: Say Goodbye To Classic Concrete - The Tiny Life*, n.d.).

However, hempcrete has a low rate of compressive strength (Barbhuiya & Bhusan Das, 2022) and the cost is higher than conventional materials. "Hemp fibres have a two to four times higher cost price compared to conventional materials such as glass and mineral wool that are currently dominating the market" (Ingrao et al., 2015).

2.7.1.1. Application

"Hempcrete can be mixed in various proportions as well as applied in a range of thicknesses to reach desired insulation ratings" (Malloy & Gonzalez, n.d.). It may be applied in walls, attics, within floor structures, and plaster finishes.

Hempcrete "can be used to create blocks or panels that would replace other exterior cladding materials" (Malloy & Gonzalez, n.d.). Hempcrete is also able to "replace petrochemically based insulation products" because of its thermal properties (Malloy & Gonzalez, n.d.). A hempcrete wall system can be applied using on-site mixes, precast hempcrete blocks, and prefabricated hempcrete panels.

Prefabricated hempcrete wall systems "can cure separately from the overall building and be set in place when ready" (Malloy & Gonzalez, n.d.). Manufacturing panels off-site minimizes drying times, quickens assembly times, lowers the labor requirements, and reduces the chance of thermal bridging as it fills the entire wall cavity and it is fire-resistant (Malloy & Gonzalez, n.d.).

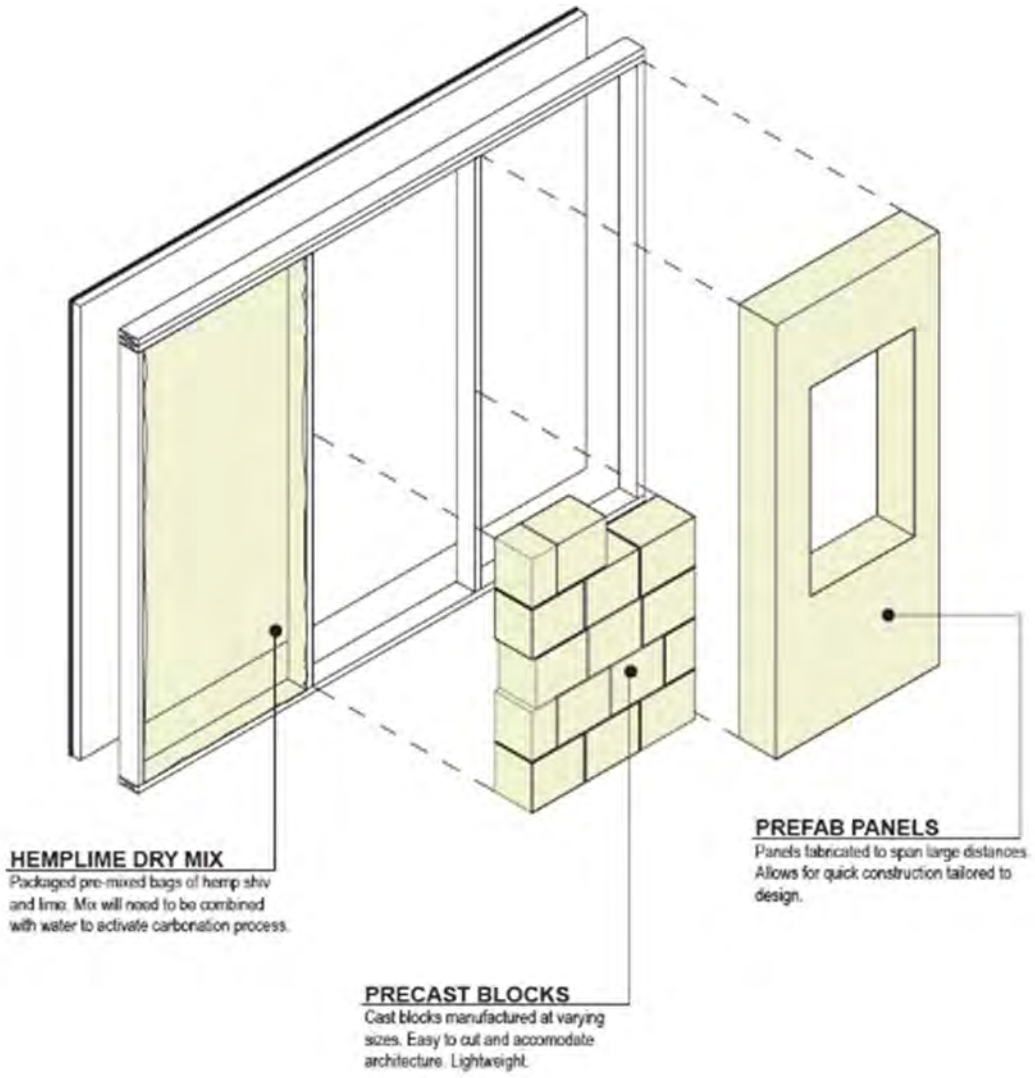

Figure 9. Hempcrete Wall Systems
Note: Malloy, I., & Gonzalez, M. (n.d.). *Director, Alison Mears AIA LEED AP Director of Design, Jonsara Ruth*.

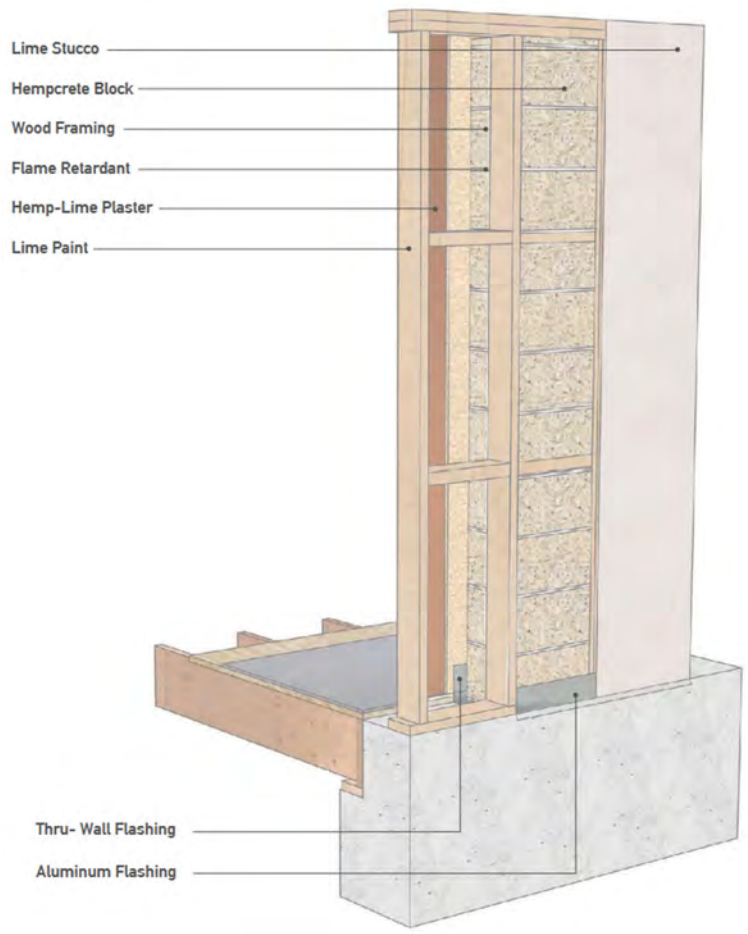

Figure 10. Hempcrete Block and Wood Frame Assembly
Note: Malloy, I., & Gonzalez, M. (n.d.). *Director, Alison Mears AIA LEED AP Director of Design, Jonsara Ruth*.

2.7.1.2. Future Research of Hempcrete

Hemp concrete like sandwich panels and modular systems should also be researched in the future (Barbhuiya & Bhusan Das, 2022).

Currently there is no UL rating for Hempcrete. “The United States Hemp Building Association is working towards that goal, but it is extremely expensive so that has been the main constraint so far” (Matt Marino, Homeland Hempco).

2.7.2. Structural Insulated Panels (SIPs)

Structurally insulated panels (SIPS) have exceptional thermal performance, create a healthier indoor air quality, contain some sustainable aspects, and can help increase the time of construction with less labor. “The panels consist of an insulating foam core sandwiched between two structural facings, typically oriented strand board (OSB)” (*What Are Sips*, n.d.). SIPS are made off-site in a controlled environment and can be made to fit almost any design, which results in a strong, energy-efficient, and cost-effective building system (*What Are Sips*, n.d.).

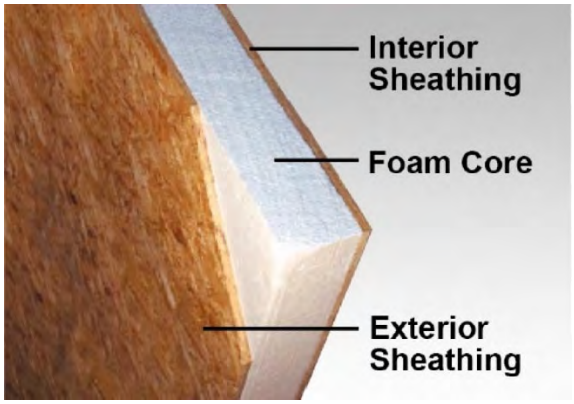

Figure 11. Typical SIP Construction
Note: *What Are Sips*. (n.d.). Retrieved February 11, 2024, from https://www.sips.org/what-are-sips

“SIPS are known to be about 50% more energy-efficient than traditional timber framing” (*What Are Sips*, n.d.). There is minimal thermal bridging in a SIP building, which makes it ideal for LEED and net-zero ready building standards (*What Are Sips*, n.d.). Structural insulated panels “have an insulation layer that provides high thermal resistance and is placed between concrete wythes and joined using mechanical connectors” (Mugahed Amran et al., 2020).

In a SIP building there is more control over the air quality as “the airtight building envelope limits incoming air to controlled ventilation which filters out the contaminants and allergens” (*What Are Sips*, n.d.).

SIPs can also be sustainable as they are “highly energy efficient and therefore contribute positively to the environment by reducing CO2 levels” (*What Are Sips*, n.d.). Less energy is also used “during the manufacturing process compared to traditional construction methods and have

lower embodied energy than traditional construction materials, such as steel, concrete, and masonry" (*What Are Sips*, n.d.).

Lastly, because the panels are produced offsite, the onsite assembly time is quick and "made watertight in a matter of days" (*What Are Sips*, n.d.). "This reduces costs such as project management, scaffolding, framing labor, and much more" (*What Are Sips*, n.d.).

There are some disadvantages to SIPs such as there is little room for future modification opportunities when the building has been constructed. These may include "smaller renovations like adding plumbing or electrical lines...as all of the holes for these systems come pre-drilled" (*The Pros and Cons of Building with SIPs - Dice Consulting*, n.d.).

2.7.3. Fiberglass Batt Insulation

Fiberglass is made of glass. "Batt insulation is made out of fiberglass or mineral wool which is pre-cut into flat pieces" (HayesCo, 2019). It is inexpensive and is typically placed in between studs, and it can be used in walls, ceilings, and floors. "Batt is very flexible so it can be fit into framing to reduce heat transfer and help reduce energy bills" (HayesCo, 2019).

"Fiberglass batts are cost-effective, easy to install, and readily available. They provide good thermal performance, are non-combustible, and allow for more breathability within your walls, reducing the risk of moisture buildup" (DeVere, 2019). The cost to install fiberglass varies depending on location, however "the average cost to install fiberglass insulation starts at $.088 to $1.64 per square foot" (Orentas, 2024). Fiberglass batts are common and easy to find at most supply stores. This type of insulation has a high R-value which leads to energy savings and a more comfortable environment. "Fiberglass and mineral wool insulation can be recycled, but most facilities do not have the proper equipment available to handle the job" (*How to Dispose of Insulation*, n.d.).

There can be some drawbacks to fiberglass batt. It "can be itchy and irritating to handle, and inhaling the fibers can cause respiratory problems" (*Fiberglass Batt Insulation*, n.d.).

“Additionally, fiberglass batts are not resistant to moisture, mold, and mildew, which can be a concern in areas with high humidity or potential water leaks” (*Fiberglass Batt Insulation*, n.d.).

In conclusion, fiberglass batts are a cost-effective solution, easy to install and readily available, and are a highly insulative product. However, it can be dangerous to install fiberglass batt if safety considerations are not taken.

Figure 12. Fiberglass Batt Insulation
Note: Orentas, G. (2024, March 19). *Learn The Pros And Cons Of Fiberglass Insulation*. Forbes Home. https://www.forbes.com/home-improvement/insulation/what-is-fiberglass-insulation/

2.7.4. Rigid Foam

Rigid foam insulation typically comes as expanded polystyrene foam, extruded polystyrene foam, and rigid polyurethane foam. “Rigid foam board insulation has a high insulating value relative to its thickness, providing optimal insulation for small spaces like framed walls” (“Rigid Foam in Baltimore, MD,” n.d.). It is ideal for masonry cavity walls, framed walls, pre-engineered metal buildings, and crawl spaces (“Rigid Foam in Baltimore, MD,” n.d.).

Some benefits of rigid foam insulation include improvement of indoor air quality, high R-value, controls moisture, minimal maintenance, seamless compatibility with various building materials, and the reduction of heating and cooling costs for lower energy bills (“Rigid Foam in Baltimore, MD,” n.d.). However, “It can have a higher upfront cost compared to other insulation choices, but your continuous return on investment (ROI) makes the initial investment well

worth it" ("Rigid Foam in Baltimore, MD," n.d.). It also does not provide much structural strength ("Rigid Foam in Baltimore, MD," n.d.).

Figure 13. Rigid Foam Insulation
Note: Rigid Foam in Baltimore, MD. (n.d.). *Devere Insulation*. Retrieved April 2, 2024, from https://devereinsulation.com/insulation-products/rigid-foam-insulation/

2.7.5. Spray Foam Insulation

Spray foam insulation "combines insulation and air sealing" ("Spray Foam in Baltimore, MD," n.d.). "Foam insulation is applied as a liquid that quickly expands to fill a space. Such complete coverage prevents air leakage and keeps energy bills low" ("Spray Foam in Baltimore, MD," n.d.). It is "durable, stable, and long-lasting, and can be used on walls, roofs, attics, and inaccessible areas. It can also increase the strength of your home by helping to provide more stability during high winds and severe storms" ("Spray Foam in Baltimore, MD," n.d.).

Spray foam insulation "has its own unique benefits, such as air sealing and insulating your home in one easy step as an expanding liquid foam" (DeVere, 2019). Other benefits include greater energy efficiency, advanced moisture management, better temperature control, noise reduction, improved air leak prevention, never sags, settles, or shrinks, and adds to the building stability ("Spray Foam in Baltimore, MD," n.d.). However, once spray foam insulation is installed, it cannot be recycled or reused.

Figure 14. Spray Foam Insulation
Note: Spray Foam in Baltimore, MD. (n.d.). *Devere Insulation*. Retrieved April 2, 2024, from https://devereinsulation.com/insulation-products/spray-foam/

2.8. Siding Materials

Several types of siding have varied factors that determine how sustainable they are such as material, recyclability, labor, and efficiency (Pantzer, 2023). It is important that the siding materials chosen are breathable and non-toxic. The walls do not need to technically "breathe," but the people inhabiting the building should be able to. Importantly, walls should be able to dry out when they get wet as they should not be trapping any moisture in. Some common types of siding materials include wood, vinyl, metal, fiber cement, and composite siding.

2.8.1. Wood Siding

"Wood is a non-toxic, biodegradable, and naturally occurring material" (Pantzer, 2023). It is "an energy-efficient and insulating material," but "it is also prone to damage from the elements, making it less eco-friendly than other longer-lasting materials" (Pantzer, 2023). It "can be recycled at the end of its lifespan, which significantly boosts its overall sustainability score" (Pantzer, 2023).

2.8.2. Vinyl Siding

"Vinyl siding is one of the most low-maintenance, energy-efficient, and lightweight products on the market. It is easy to install, requires less labor, and lasts decades" (Pantzer, 2023). However, it is "made from polyvinyl chloride (PVC)—a manufactured material that is not good for humans or the environment. When exposed to heat, it can release toxic components into the atmosphere, like chlorine gas, and it is challenging to recycle" (Pantzer, 2023).

2.8.3. Metal Siding

"Many metal siding boards are made from recycled metals, like aluminum and steel, that can be recycled at the end of their lifespan. Metal is also a long-lasting material that requires minimal maintenance" (Pantzer, 2023). During the manufacturing process, "metal siding production requires nonrenewable energy sources and a significant amount of labor. Additionally, metal siding is not as energy efficient as other materials, requiring your home's heating and cooling systems to work harder" (Pantzer, 2023).

2.8.4. Fiber Cement Siding

"Fiber cement siding is one of the most eco-friendly products available to homeowners" (Pantzer, 2023). Fiber cement siding is made from natural materials "like sand and wood fibers, and are highly durable, low-maintenance, and long-lasting" (Pantzer, 2023). It is also recyclable and reuseable at the end of its lifespan. (Pantzer, 2023). Installation can be difficult, but since it is commonly used, "many manufacturers are well-versed in installing this material properly" (Pantzer, 2023).

2.8.5. Composite Siding (Engineered Wood Siding)

This type of siding "is made from sustainable, biodegradable scrap wood bound together with polymer resins often sourced from recycled plastics" (Pantzer, 2023). While it is not as sustainable as wood, it is "more sustainable than boards made from 100% plastic" (Pantzer, 2023). "Composite siding is durable, long-lasting, and easy to install, but only some composite siding materials are recyclable" (Pantzer, 2023).

Engineered wood siding typically costs between $3.58 to $8.58 per square foot to install (*2024 Engineered Wood Siding Costs | Installation Price Guide*, n.d.).

2.9. Photovoltaic Panels

"Photovoltaic (PV) devices generate electricity directly from sunlight via an electronic process that occurs naturally in certain types of material, called semiconductors" (*Photovoltaics | SEIA*, n.d.). PV systems do not have to be attached to a roof top or structure for domestic applications (*Stand Alone PV System for Off-Grid PV Solar Power*, 2023). Photovoltaic cells are connected to create a solar panel (Dallas, 2018). There are two types of PV systems: A grid-connected PV system and a stand-alone PV system.

A stand-alone PV system is a more cost-effective option for rural areas where other power sources are unavailable (*Stand Alone PV System for Off-Grid PV Solar Power*, 2023). A small gas or diesel generator is included for extended no-sun periods (*Stand Alone PV System for Off-Grid PV Solar Power*, 2023).

"The average cost of a solar panel installation in 2023 ranges from $17,430 to $23,870 after taking into account the federal solar tax credit, with an average solar installation costing about $20,650" (How Much Do Solar Panels Cost in 2023? | EnergySage, n.d.). In Minnesota, the payback period of a solar panel system will take 12.65 years, with a 20-year savings of $20,065 at a Cost per Watt rate of $3.43 (Minnesota Solar Panel Cost, n.d.).

There are some advantages and disadvantages to PV panels. PV panels have a longer life span, do not freeze over the winter, are more multi-purpose as they produce electricity, and have a low-maintenance cost because there are no moving parts (*Photovoltaic Panels Vs Solar Panels*, 2023). However, they have a high-initial cost, an efficiency of only 15 to 20%, and difficult to install (*Photovoltaic Panels Vs Solar Panels*, 2023).

2.10. Solar Thermal

Solar thermal panels rely on the sun to produce energy, but solar thermal panels harvest energy to create only heat (*Solar Thermal vs Solar PV Panels*, n.d.). The panels capture energy

to provide hot water. There are two types of solar panels used for this (*Solar Thermal vs Solar PV Panels*, n.d.).

One type of solar thermal panels are flat-plate collectors. Flat-plate collectors are like PV panels, "in that they're flat, dark plates mounted on a roof" (*Solar Thermal vs Solar PV Panels*, n.d.). They consist of a black surface (absorber plate), support structure, glazing sheet, and copper pipes or tubes.

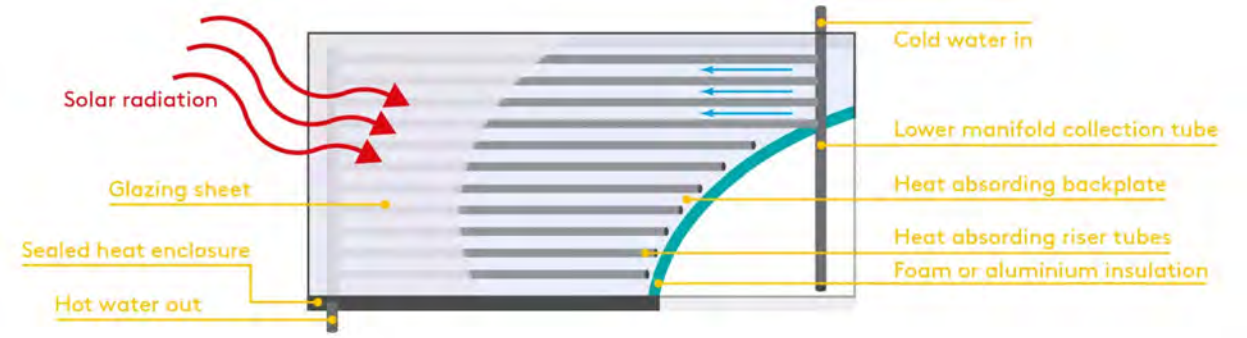

Figure 15. Flat-Plate Collector.
Note: Solar thermal vs solar PV panels. (n.d.). Retrieved November 7, 2023, from https://www.essentracomponents.com/en-us/news/industries/renewable-energy/solar-thermal-vs-solar-pv-panels

The other form of solar thermal panels are evacuated tube collectors. Evacuated tube collectors "are more efficient than flat-plate panels, particularly in cold weather," but risk overheating in warmer temperatures (*Solar Thermal vs Solar PV Panels*, n.d.). The components of an evacuated tube collector are transparent glass tubes, absorber plates, and heat pipes.

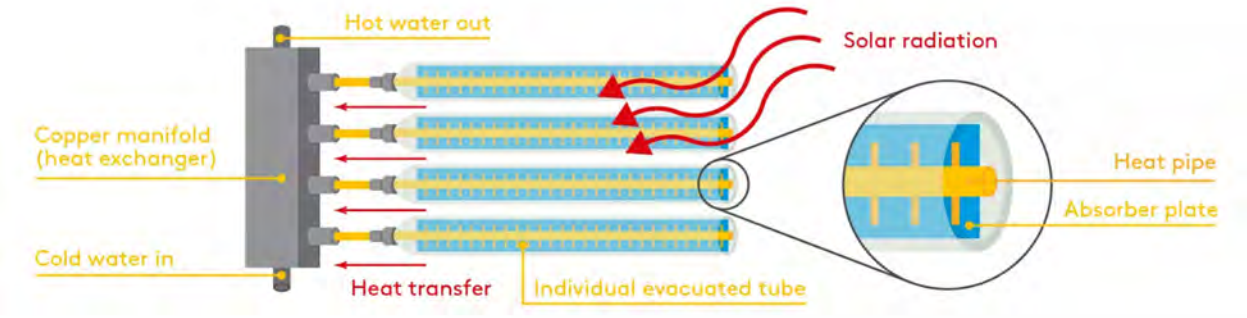

Figure 16. Evacuated Tube Collector.
Note: Solar thermal vs solar PV panels. (n.d.). Retrieved November 7, 2023, from https://www.essentracomponents.com/en-us/news/industries/renewable-energy/solar-thermal-vs-solar-pv-panels

The pros of solar thermal are that is a renewable source of energy, zero carbon emissions, and minimal maintenance. The cons are that it is an expensive upfront cost, inconsistent, and storage – hot water will lose heat if stored for a prolonged period (*Solar Thermal vs Solar PV Panels*, n.d.).

2.11. Net Zero Water Building Strategies

A net zero water building "minimizes total water consumption, maximizes alternative water sources, and minimizes wastewater discharge from the building and returns water to the original water source" (*Net Zero Water Building Strategies*, n.d.). "A net zero water building completely offsets water use with alternative water plus water returned to the original water source" (*Net Zero Water Building Strategies*, n.d.). The building should be located within the watershed of the original source (*Net Zero Water Building Strategies*, n.d.).

To measure net zero water, you take the alternative water use plus water returned divided by the total water use.

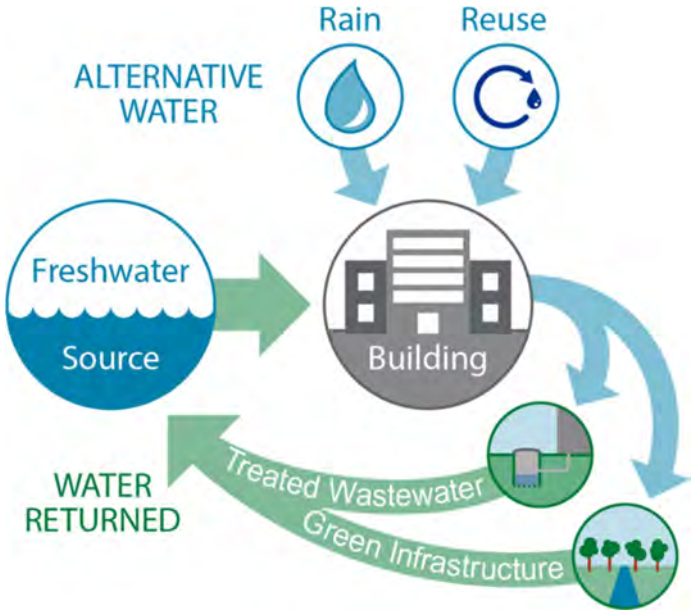

Figure 17. Net-Zero Water Process.
Note: https://www.energy.gov/femp/net-zero-water-building-strategies

2.12. Housing Assistance Programs

There are several Housing Assistance Programs and or grants available in Minnesota to residents as well as developers to help offset the cost of constructing low-income and sustainable housing.

2.12.1. Affordable Housing Plan (2024-2025)

"The Affordable Housing Plan (AHP) is Minnesota Housing's business plan to carry out the Agency's core work for the upcoming two years and implement the Strategic Plan. The AHP outlines key programmatic and policy initiatives for the next two years, specifies program-by-program funding and establishes production targets" available (*Agency Plans*, n.d.).

2.12.1.1. Funding Sources

There is an estimated amount of program investments for each funding source for the 2024-2025 year. These funding sources include Federal Resources, State Appropriated Resources, Mortgage Capital from Bond or Agency Resources, and the Housing Affordability Fund (Pool 3).

Federal Resources has an estimated amount of $646,053,700 available (*Agency Plans*, n.d.). Federal Resources include the U.S. Department of Housing and Urban Development (HUD) that make available appropriations "to Minnesota Housing and Low-Income Housing Tax Credits from the Internal Revenue Service (IRS)" (*Agency Plans*, n.d.).

State Appropriated Resources has an estimated amount of $1,286,619,000 available (*Agency Plans*, n.d.). "The amount of funding is based on the 2024-2025 general fund budget adopted by the 2023 Minnesota Legislature. Any unused funds from previous year appropriations and repayments of loans are included" (*Agency Plans*, n.d.).

Mortgage Capital from Bond or Agency Resources has an estimated amount of $2,551,968,000 available (*Agency Plans*, n.d.). Some of these resources come from the state capital budget, others come from bond proceeds that "are generated by the issuance of tax-exempt and taxable bonds" (*Agency Plans*, n.d.), as well as earnings generated from lending and

investment activities and reinvesting them in a wide variety of housing programs (*Agency Plans*, n.d.).

The Housing Affordability Fund (Pool 3) has an estimated amount of $48,730,000 available (*Agency Plans*, n.d.).

2.12.2. U.S. Department of Housing and Urban Development (HUD)

"HUD awards discretionary funding through over 20 Grant programs that support HUD initiatives, including Affordable Housing Development and Preservation, Community and Economic Development, Environment and Energy, Fair Housing, Homelessness, Homeownership, Rental Assistance, Supportive Housing and Services" (*Funding Opportunities*, n.d.).

2.12.3. Minnesota Housing, Housing Development and Capital Funding Programs

These capital program funding options are available for rental properties throughout Minnesota. They are in place to help increase affordable housing.

2.12.3.1. Housing Tax Credits

"The Low-Income Housing Tax Credit (HTC) Program awards and allocates federal tax credits to owners of qualified affordable rental housing projects. These HTCs, which offer a 10-year reduction in tax liability, are sold to investors in exchange for capital to build eligible affordable rental housing units in new construction, rehabilitation, or acquisition with rehabilitation" (*Housing Tax Credits*, n.d.).

2.12.3.2. Deferred Loan and Grant Programs

"Deferred loans and grant programs are available throughout the year. Deferred loans are structured as repayable loans at 0% for a term of 30 years" (*Deferred Loans and Grant Programs*, n.d.).

2.12.4. Minnesota Housing – Clean Energy Resources for Multifamily Affordable Housing

This section will go through some of the different programs that are in place to help with utility costs for multifamily affordable housing.

2.12.4.1. Minnesota Energy Resources – Multifamily Energy Savings Program

"This program includes the direct installation of high-efficiency showerheads and faucet aerators where appropriate to the buildings' operations. Additional opportunities for energy savings will be evaluated, including: assessment of centralized heating systems; building operations opportunities, such as boiler control settings; flow measurements and diagnosis of central ventilation systems; a customized energy report with recommendations; follow up assistance with high-value savings opportunities; rebate incentives for energy-efficiency measures most common to multifamily buildings. All of this is at no cost. The program covers all materials and time, no matter how large your building" (*Clean Energy Resources*, 2021).

2.12.4.2. Ottertail Power – House Therapy

"The House Therapy program can help make your home more efficient and help cut costs on your monthly energy bills. The House Therapy program offers free energy-saving services to replace inefficient appliances and weatherize homes for qualified customers as well as for low-income multifamily buildings and homes" (*Clean Energy Resources*, 2021).

2.12.5. Minnesota Healthy Housing Grants

The Minnesota Department of Health Lead and Healthy Homes Program (LHHP) offers grants to "provide funding to perform activities related to housing-based health threats" (*Healthy Housing Grants - MN Dept. of Health*, n.d.).

3. METHODOLOGY / APPROACH

This section discusses site analysis, diagrams, case studies, site/space program, as well as inspiration.

3.1. Site Selection

The site I have chosen is in upper Duluth, MN. It is a 20-acre site that is currently listed at $300,000. There is a small stream that runs through the site starting in the northwest corner and ending in the middle of the south part of the site. The site has a total elevation change of thirty feet with 1130 feet being the highest point and 1100 feet being the lowest point. There are various forms of vegetation on the site including deciduous and coniferous trees. Fitger Road is currently an unpaved road. The site is about a 20-minute drive from downtown Duluth.

Figure 18. Site Location
Note: County Land Explorer. (n.d.). Retrieved October 25, 2023, from https://gis.stlouiscountymn.gov/landexplorer/

The site is also located in the French River/Palmer neighborhood of Duluth. This neighborhood has an A+ overall safety ranking. I took this into consideration as well, as most of the lower priced homes are in unsafe neighborhoods, and I wanted there to be an option for low-income residents to live in a safer area.

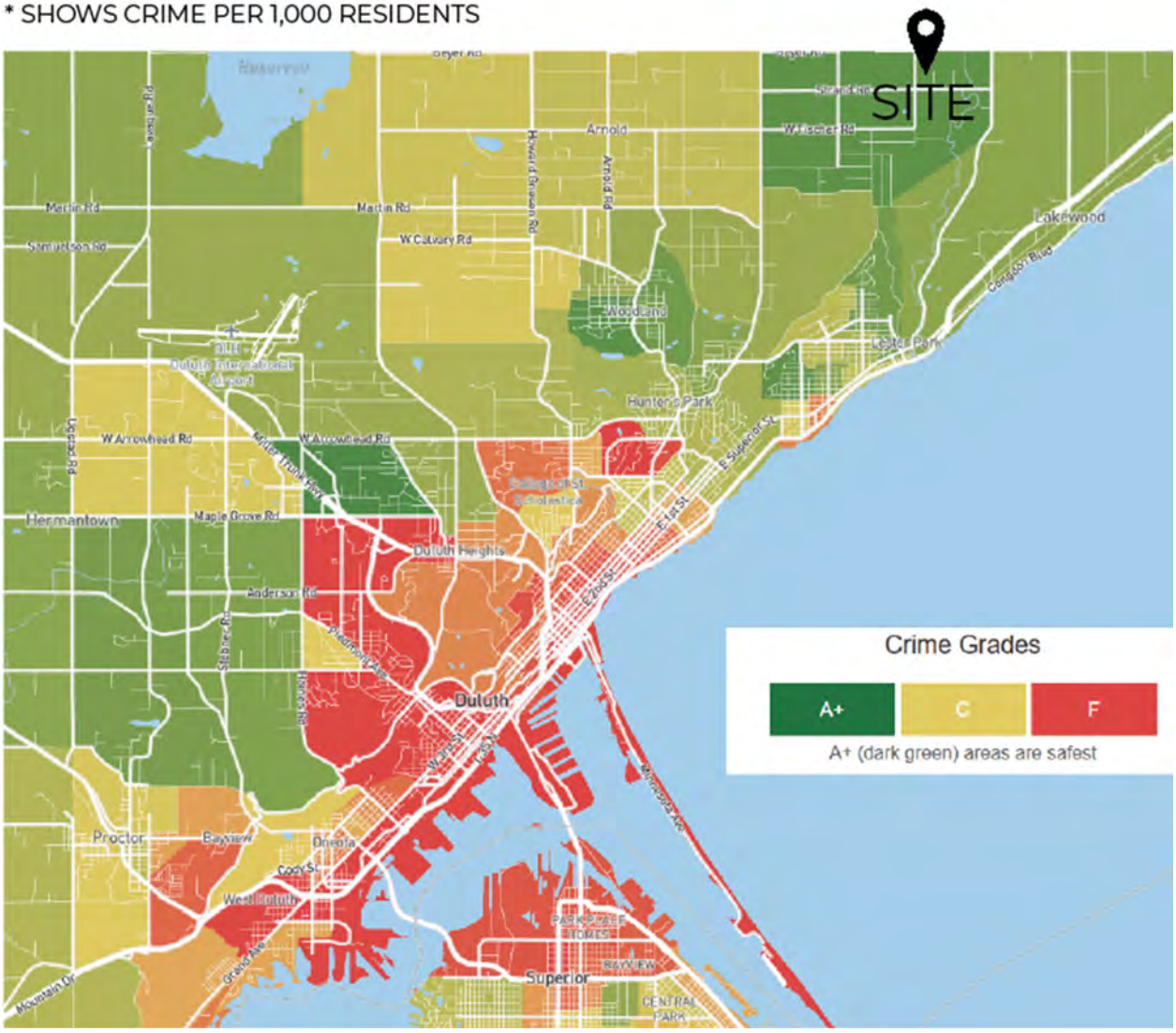

Figure 19. Crime Map Duluth
Note: The Safest and Most Dangerous Places in Duluth, MN: Crime Maps and Statistics. (2023, February 28). CrimeGrade.Org. https://site.crimegrade.org/templates/safest-places-in-place-slug/

Figure 20. Aerial Image of the Site
Note: County Land Explorer. (n.d.). Retrieved October 25, 2023, from https://gis.stlouiscountymn.gov/landexplorer/

Figure 21. Aerial Image of the Site
Note: County Land Explorer. (n.d.). Retrieved October 25, 2023, from https://gis.stlouiscountymn.gov/landexplorer/

Figure 22. Fitger Road
Note: Picture taken standing on Fitger Road (North of the site) looking West. (11/11/2023)

Figure 23. Fitger Road
Note: Standing on Fitger Road (North of the site) looking East (11/11/2023)

Figure 24. Site
Note: Standing on Fitger Road (North of the site) looking South (11/11/2023)

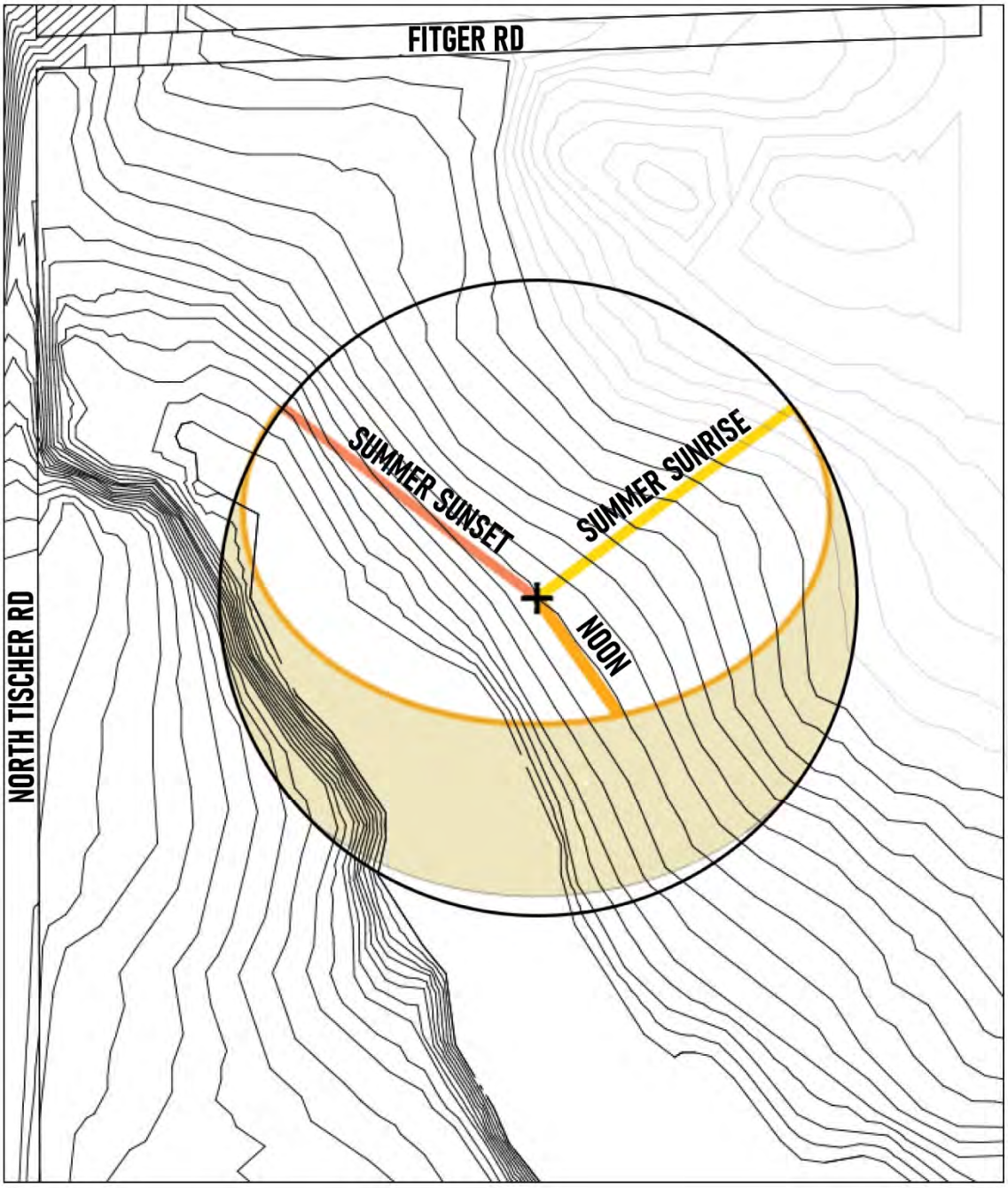

Figure 25. Summer Sun Path Study
Note: Lightly shaded contour lines are elevations to be leveled.

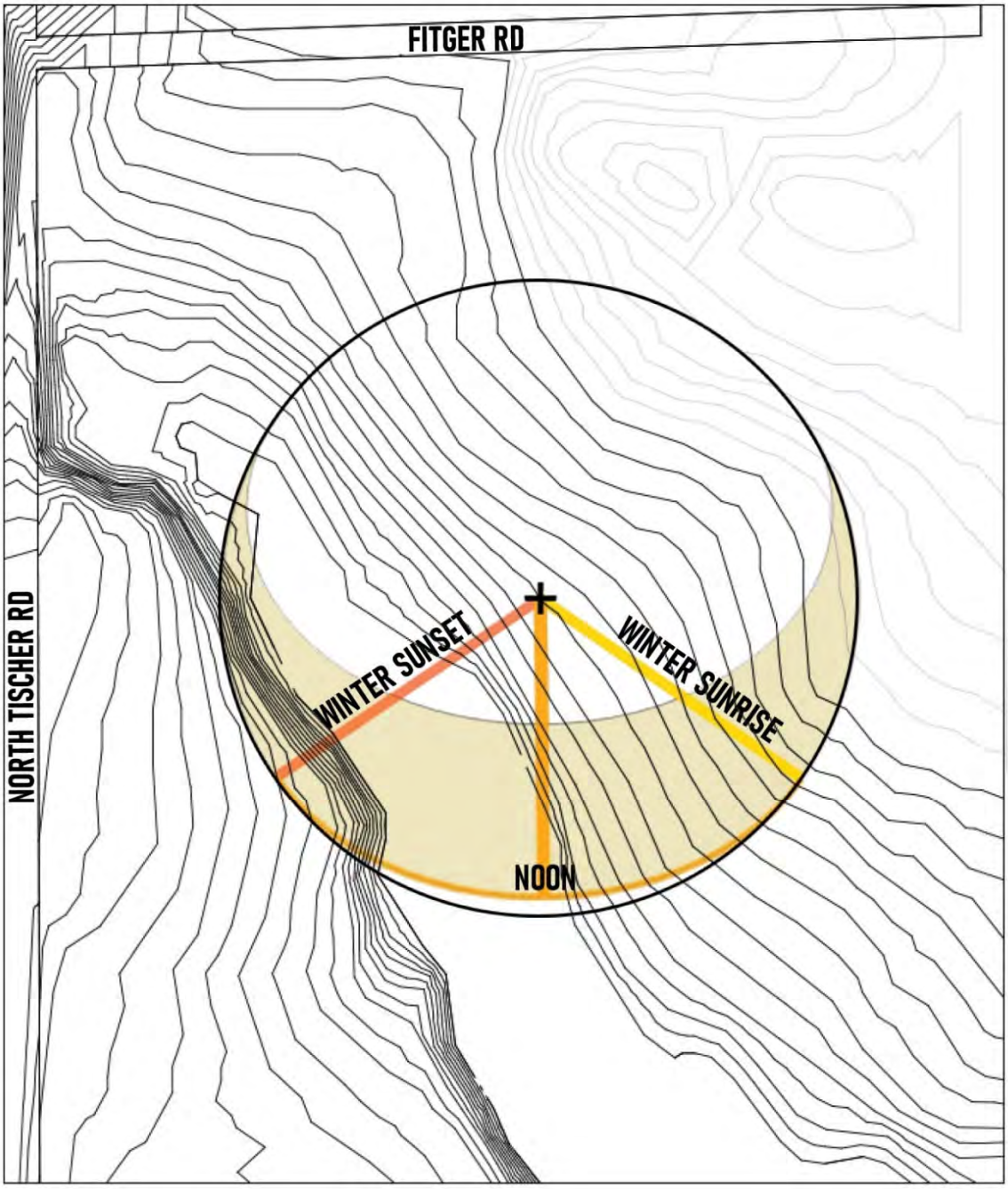

Figure 26. Winter Sun Path Study
Note: Lightly shaded contour lines are elevations to be leveled.

3.2. Case Studies and Precedent Studies

The case studies will discuss the different affordable and sustainable housing case studies/projects that have been completed.

3.2.1. Affordable, Net-Zero Housing Development in Colorado

There is a 20-unit development project for affordable, and net-zero housing in Colorado. To make the development a reality, certain deals were made with the government to help offset the cost, but not all. The housing units sold for $125,000, which only covered 60% of the development's $9 million cost. The rest of the funding "came from state and federal grants, corporate donations, and partnerships with Holy Cross Energy" (Shaw, 2023).

Figure 27. Affordable Housing Construction
Note: (N.d.). Retrieved December 4, 2023, from https://www.hcn.org/articles/south-housing-can-net-zero-homes-really-be-affordable/apartment_block_at_wapiticommons_rifleco-jpg/image_view_fullscreen

3.2.2. Mixed-Use and Environmentally Sustainable Net-Zero Affordable Housing in Colorado

The Boulder County Housing Authority (BCHA) created a plan for a large net-zero affordable neighborhood, "Willoughby Corner," that will be completed in Lafayette in 2024. The

neighborhood will “bring 400 new rentals and for sale affordable homes to Lafayette when fully complete” (Milehighcre, 2023). The homes will be available for individuals or families “earning at or below 60 percent of the Area’s Median Income” (Milehighcre, 2023). The development will sit on twenty-four acres of land. It includes ADA accessible apartments, multi-family homes, and a community center (Milehighcre, 2023). The buildings will “utilize solar and geothermal technology and incorporate highly energy-efficient building designs and materials” (Milehighcre, 2023). Willoughby Corner is possible because of the city’s financial support and the county commissioners’ help with funding (Milehighcre, 2023).

Figure 28. Willoughby Corner Neighborhood.
Note: Milehighcre. (2023, May 8). Construction of Colorado’s Largest Net-Zero-Ready Affordable Housing Development Underway. Mile High CRE. https://milehighcre.com/construction-of-colorados-largest-net-zero-ready-affordable-housing-development-underway/

3.2.3. A Net-Zero Energy Low-Income Residential Housing Development in Lafayette, Colorado

This report outlines lessons learned of "an ultra-low-energy single-family ranch home and duplex unit and presents the final design recommendations for a 153-unit net zero energy residential development" (Dean et al., n.d.). The report discusses the processes used to design and construct the project. The housing project used modular, systems-built construction, ground source heat pumps with de-super heaters for domestic hot water, condensing gas furnaces, energy recovery ventilators, automated natural ventilation, evacuated solar tube hot water systems, and building integrated photovoltaic with micro inverters (Dean et al., n.d.). The use of systems-built assembly reduces the installation costs.

The report concludes that an all-electric home with a ground source heat pump, domestic hot water, super insulated building envelope construction elements, and roof-mounted photovoltaic system to be the most cost-effective option, and if executed correctly would result in a net-zero energy development (Dean et al., n.d.).

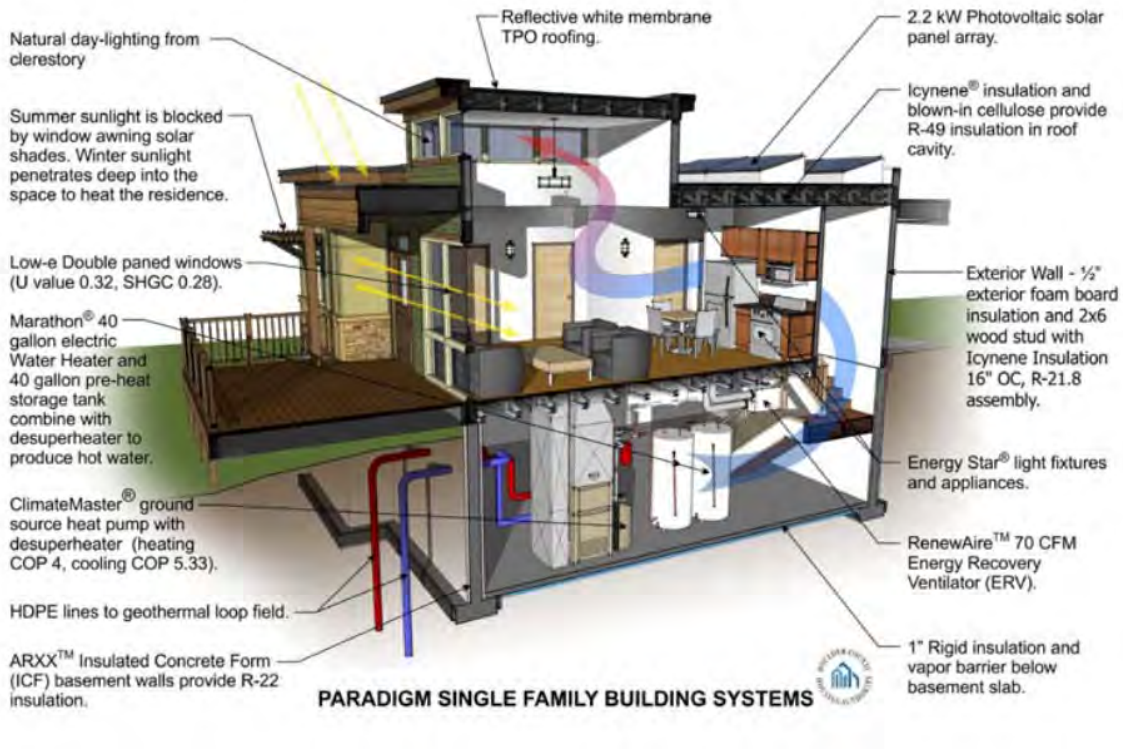

Figure 29. Single Family Net-Zero Energy Building.
Note: Dean, J., VanGeet, O., Simkus, S., & Eastment, M. (n.d.). Design and Evaluation of a Net Zero Energy Low-Income Residential Housing Development in.

3.2.4. Revelstoke's First Hemp House – Hempcrete is Meant to be a more Sustainable Building Material

Revelstoke, Canada recently had a hempcrete house constructed. Hempcrete does not "replace structural components but is used to create walls with insulative and moisture-regulating properties. It also has great mold-resistant, pest-resistant, and fire-resistant properties" (*Revelstoke's First Hemp-House - Revelstoke Review*, n.d.).

"The hemp that they used was grown in Alberta and the carbon that was sequestered during its growth is now embedded in the house" (*Revelstoke's First Hemp-House - Revelstoke Review*, n.d.). The hemp house can moderate temperature and moisture levels on its own rather than relying on an HVAC system (*Revelstoke's First Hemp-House - Revelstoke Review*, n.d.). "The insulation value of hempcrete is the same as –or higher– than traditional insulation, and

hemp is also mold-resistant, pest-resistant and fire-resistant" (*Revelstoke's First Hemp-House - Revelstoke Review*, n.d.).

Construction consisted of building the foundation first, then slab prep, electrical, and plumbing. The house was then framed with a standard 2" x 6" framing. Then the hempcrete was poured into forms around the framing and tapped down around the whole house with a 12" wall. "All of the electrical and plumbing was embedded into the hemp walls in conduit" (*Revelstoke's First Hemp-House - Revelstoke Review*, n.d.).

Although the building process was different from traditional, the price was not that different. This form of construction is recommended "to others based on connecting with people and their values. The climate crisis is something that we actually have to take responsibility for" (*Revelstoke's First Hemp-House - Revelstoke Review*, n.d.).

Figure 30. Two-Story Hempcrete House.
Note: web1_231109-rtr-hempcrete-outside_1.jpg;w=960 (JPEG Image, 960 × 1280 pixels)—Scaled (71%). (n.d.). Retrieved November 2, 2023, from https://www.bpmcdn.com/f/files/shared/feeds/gps/2023/10/web1_231109-rtr-hempcrete-outside_1.jpg;w=960

3.2.5. The House that Hemp made - Steve Barron on his off-grid, carbon-capturing house at Margent Farm

Steve Barron took over 50 acres of farmland in Cambridgeshire and began growing an organic hemp farm in May of 2017. Hemp “is fast-growing and better than commercial forestry at sequestering carbon – and its long tap roots help to regenerate the soil.” Not only that, but “Beyond the relatively light processing and transportation emissions, the materials can be understood to be carbon-neutral (or carbon-negative if you count the sequestration), which is a vast improvement on steel, concrete, or petrol-based insulations” (*The House That Hemp Made*, 2021).

The resulting structure consists of a “self-heating, open-plan glass room to intimate bedrooms and living spaces” (*The House That Hemp Made*, 2021). “The woody ‘core’ of the hemp plant was used to make ‘hempcrete’ for the exposed interior structure,” (*The House That Hemp Made*, 2021) while the exterior boasts a new corrugated hemp cladding material. This method of construction “deploys a carbon-sequestering natural material which can be returned to the soil eventually; that factors in solar, wind and biofuel as energy sources, and which can be built efficiently off-site” (*The House That Hemp Made*, 2021).

Figure 31. Corrugated Hemp Panels.
Note: The house that hemp made: Steve Barron on his house at Margent Farm. (2021, May 21). *https://www.themodernhouse.com/journal/margent-farm-steve-barron-practice-architecture/*

3.2.6. Better Cheaper Housing – Vandkunsten Architects

Better Cheaper Housing "aims at establishing fundamental social and landscape values independent of cost per square meter" (*Better Cheaper Housing*, n.d.). It was developed "with the aim to offer a significantly reduced rent without losing architectural qualities" (*Better Cheaper Housing*, n.d.).

A building module of 5 x 5-meter square is the fundamental building module and "the basic home plot is 10 x 10 meters and consists of one basic living module, and exterior 5 x 5 courtyard module, a small entrance passage and a storage module" (*Better Cheaper Housing*, n.d.). "5 x 5 modules can be added to this foundation horizontally or vertically – and apartment types thus come at 50, 75, 100, 125, 0r 150 m^2" (*Better Cheaper Housing*, n.d.).

"Room heights are 2.70 m, interior materials are light and natural. Facades are black wooden boards" (*Better Cheaper Housing*, n.d.). "The horizontal board mounted on the seam between stacked elements, emphasizes the construction method of prefabrication" (*Better Cheaper Housing*, n.d.).

Figure 32. Vandkunsten – Better Cheaper Housing Living Space
Note: *Better Cheaper Housing*. (n.d.). Retrieved September 6, 2023, from https://vandkunsten.com/en/projects/better-cheaper-housing

Figure 33. Vandkunsten – Better Cheaper Housing Site Plan
Note: *Better Cheaper Housing*. (n.d.). Retrieved September 6, 2023, from https://vandkunsten.com/en/projects/better-cheaper-housing

Figure 34. Vandkunsten – Better Cheaper Housing Entry
Note: *Better Cheaper Housing*. (n.d.). Retrieved September 6, 2023, from https://vandkunsten.com/en/projects/better-cheaper-housing

Figure 35. Vandkunsten – Better Cheaper Housing Exterior
Note: *Better Cheaper Housing*. (n.d.). Retrieved September 6, 2023, from https://vandkunsten.com/en/projects/better-cheaper-housing

3.2.7. Kingo and Fredensborg Houses, Selandia

The Kingo Houses in Zealand, Denmark were built in 1959 and in 1963. “The Kingo and Fredensborg houses share one system of organic growth based on the repetition of the same residential type” (Viva, n.d.). The main idea of both cases is to combine privacy through individual courtyards and community through shared green spaces, streets, and plazas (Viva, n.d.). “The basic housing unit adopts the universal scheme of the courtyard house, with two L-shaped wings for living spaces and a square-shaped garden” (Viva, n.d.). “Though the geometry is strictly orthogonal, the system is organic because it has the capacity to grow, within each cell in particular as well as within the whole” (Viva, n.d.).

Figure 36. Kingo Houses, Selandia
Note: Viva, A. (n.d.). *Kingo Houses, Selandia—Jørn Utzon*. Arquitectura Viva. Retrieved February 11, 2024, from https://arquitecturaviva.com/works/casas-kingo-1

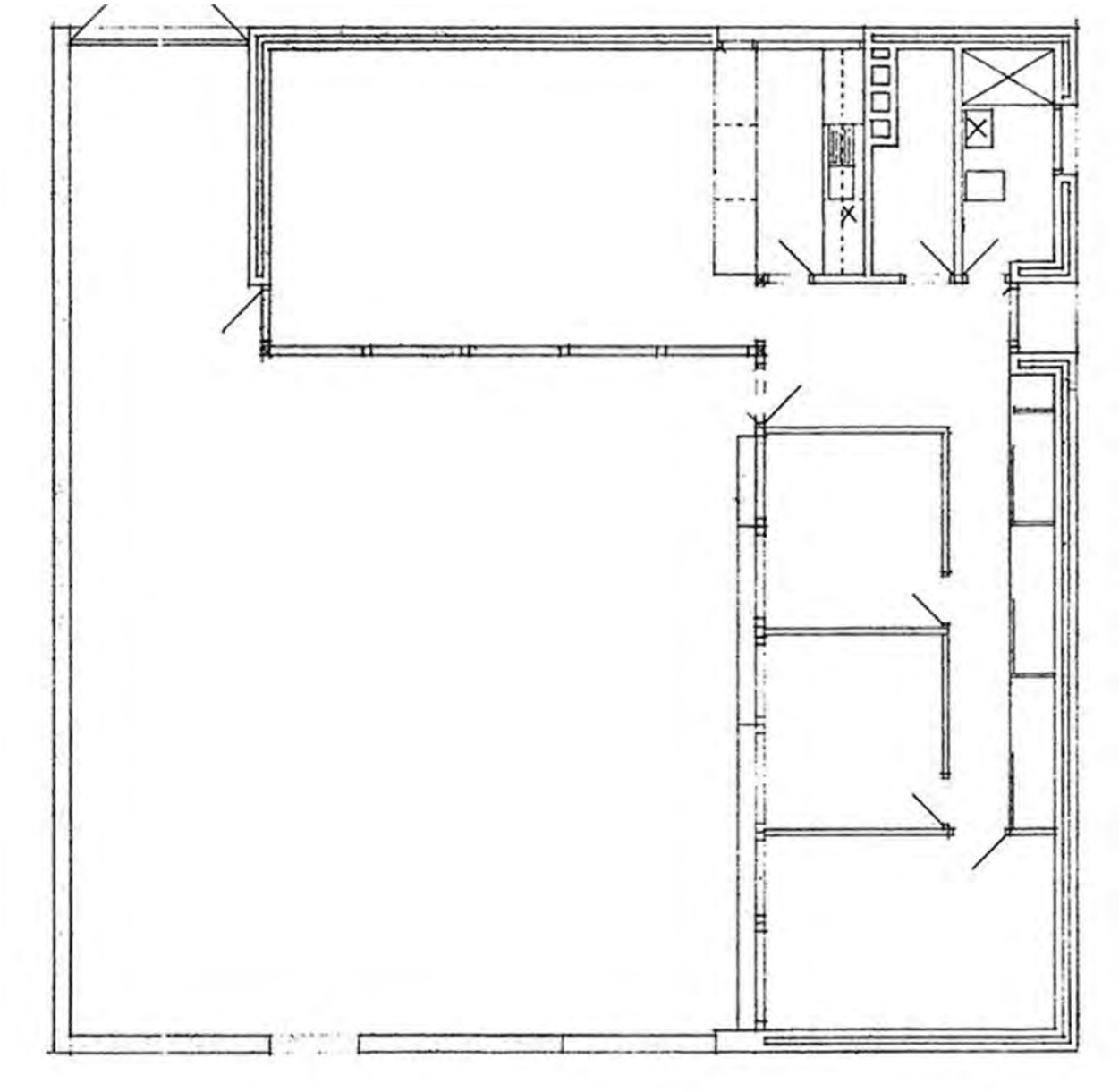

Figure 37. Kingo Houses, Selandia – Floor Plan
Note: Viva, A. (n.d.). *Kingo Houses, Selandia—Jørn Utzon*. Arquitectura Viva. Retrieved February 11, 2024, from https://arquitecturaviva.com/works/casas-kingo-1

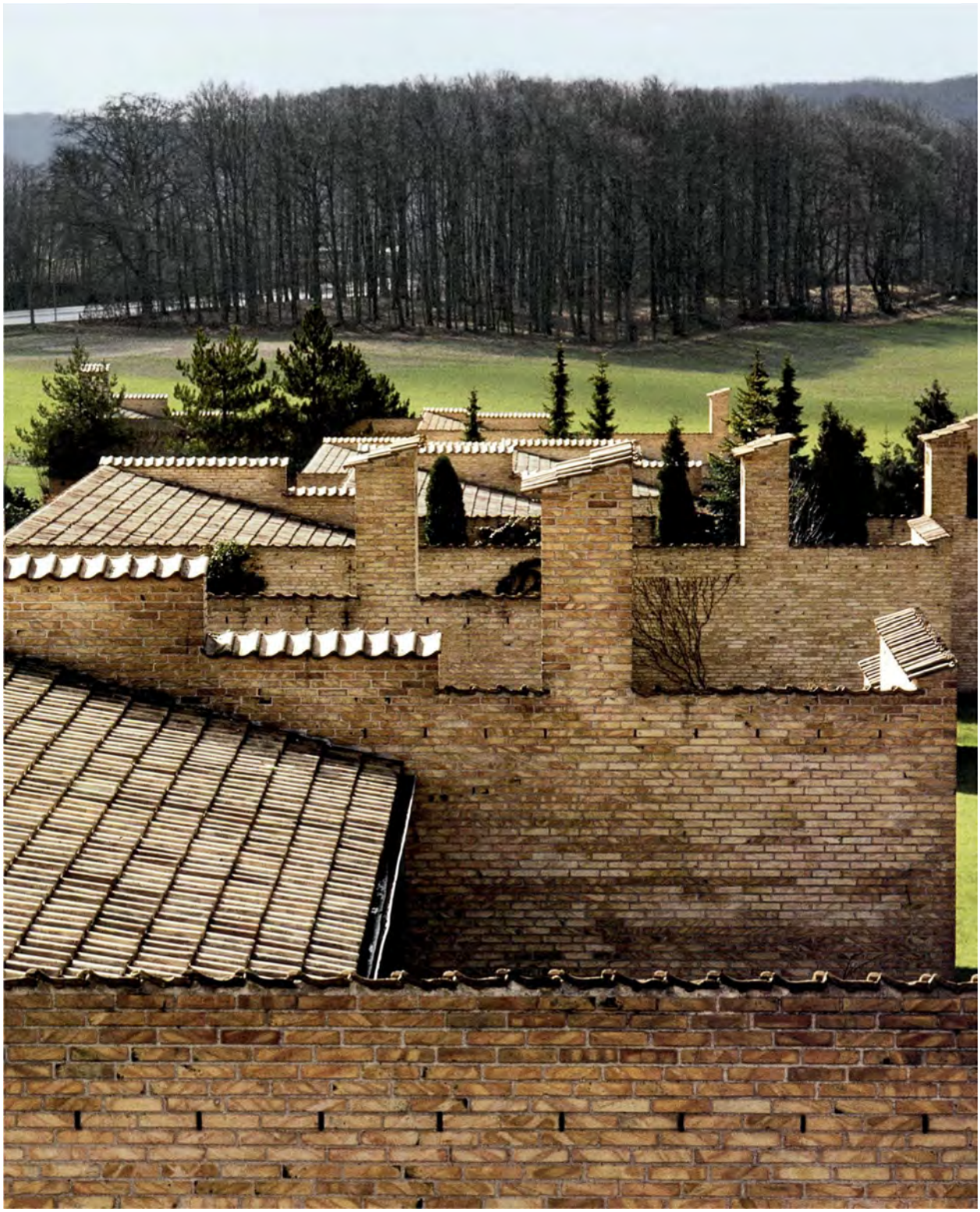

Figure 38. Kingo Houses, Selandia
Note: Viva, A. (n.d.). *Kingo Houses, Selandia—Jørn Utzon*. Arquitectura Viva. Retrieved February 11, 2024, from https://arquitecturaviva.com/works/casas-kingo-1

3.2.8. Green New Deal Housing, Superior, WI

The Green New Deal Housing Group in Superior, WI has begun constructing zero energy homes for low-income residents. “Everyone deserves to live in healthy, durable, resilient housing built to last for generations” (*PROJECTS*, n.d.). “Green New Deal Housing brings an integrated approach to community development and workforce training, to lead the transition to zero-carbon buildings and reduce the persistent racial and economic disparities in our community” (*PROJECTS*, n.d.). “Each net-zero-capable design shares the same high performance construction approach: a super-insulated building structure with triple-glazed windows and state-of-the art electric heating, cooling, and ventilation (fresh air) systems. We use durable metal siding on the exterior, available in many color options” (*PROJECTS*, n.d.). It is possible to afford these developments through grants and community funding programs.

Figure 39. Evergreen House
Note: PROJECTS. (n.d.). Greennewdealhousing. Retrieved March 24, 2024, from https://www.greennewdealhousing.org/projects

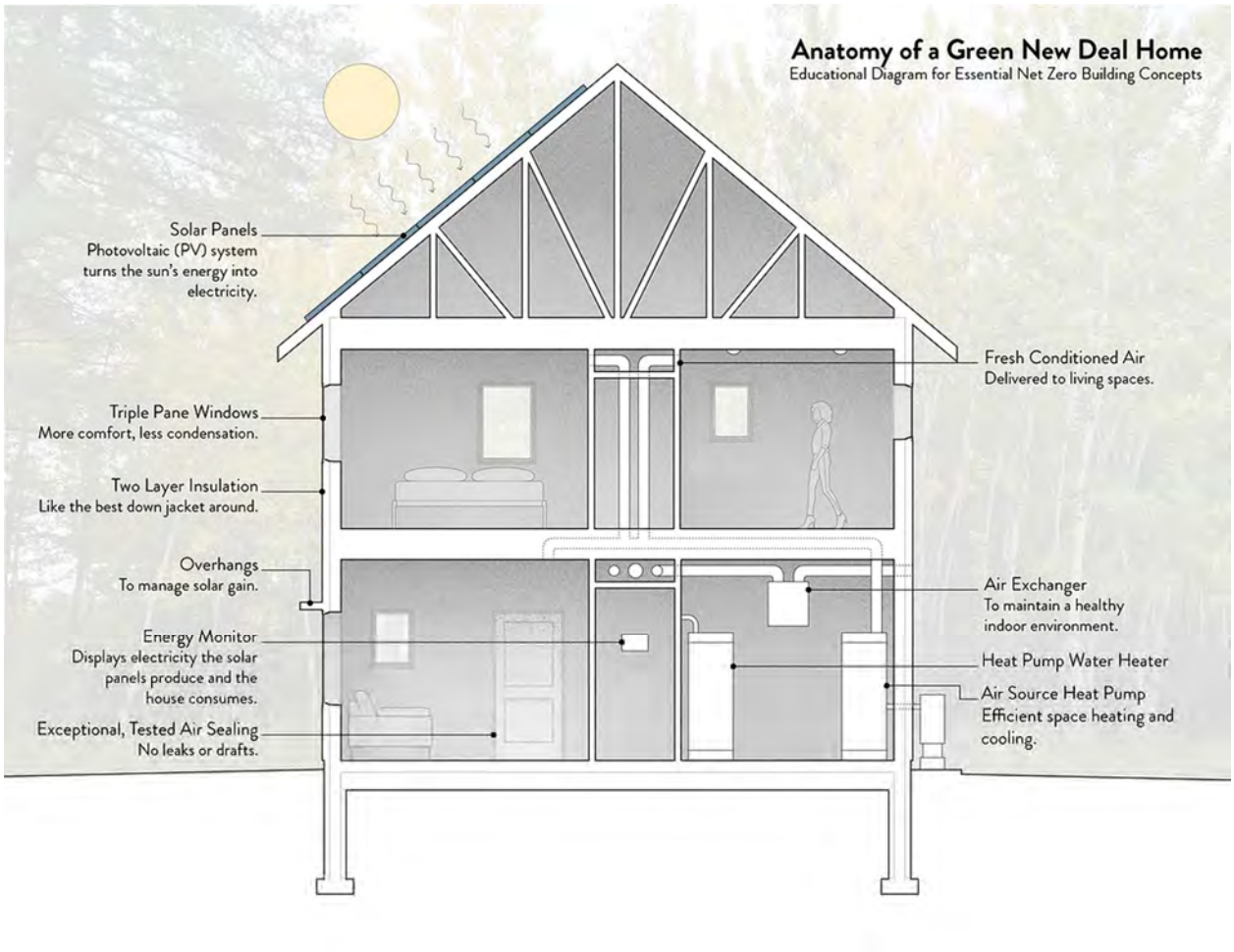

Figure 40. Anatomy of a Green New Deal Home
Note: PROJECTS. (n.d.). Greennewdealhousing. Retrieved March 24, 2024, from https://www.greennewdealhousing.org/projects

3.3. The Development

The proposed development consists of multiple dwellings that are each about 14 feet in height and shall have a footprint no larger than 1,200 square feet. The dwellings on the site should be at least 70 feet apart on the north and south sides to prevent shadows from completely covering the south sides of other dwellings. This means the dwellings have a setback of 35 feet on the north and south sides.

The dwellings use prefabricated panels (panels made off-site) for construction. Using prefabricated panels is a safer, timelier, and more cost-efficient method of construction.

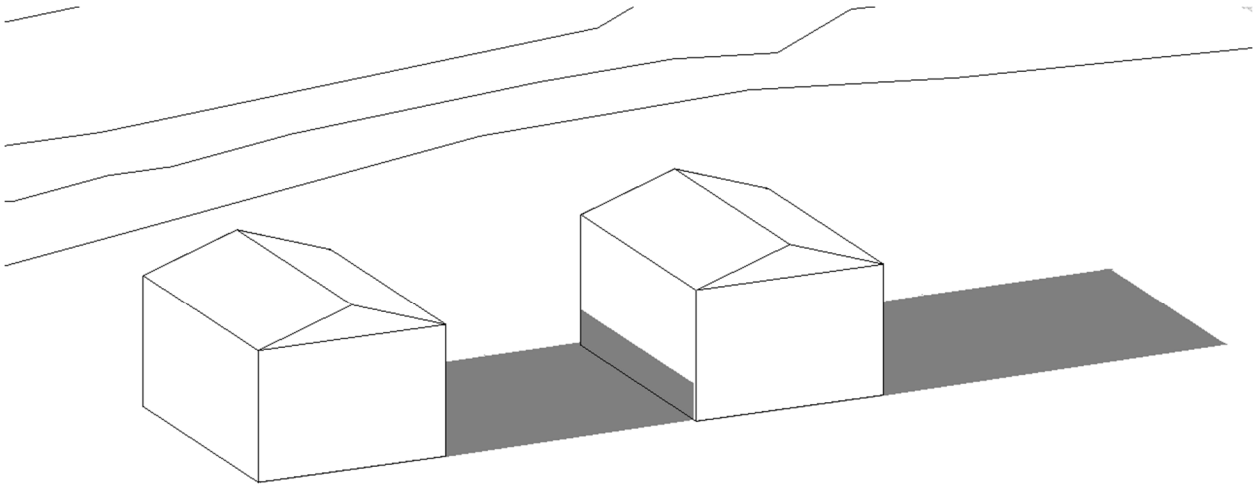

Figure 41. Shadow Study
Note: Shadows are on solar noon on December 21st, 2023

3.3.1. Two-Family Dwelling Program

The program of the two-family dwellings shall include two bedrooms, one bathroom, a kitchen, and a living space. Each two-family dwelling will be a single level above ground as a basement would increase the cost of construction. The dwellings shall share a wall, an outdoor patio, and they shall have shared parking between properties.

3.3.2. Foundation

A monolithic insulated slab-on-grade foundation shall be used for each two-family dwelling. Monolithic slabs are simple, quick, and cost-effective for construction.

The Minnesota Department of Labor and Industry requires a minimum foundation depth for the upper regions of Minnesota. St. Louis County has an Air Freezing Index (AFI) of less than or equal to 3750. Figure 37 shows a foundation design which complies with the Minnesota Residential Code and Minnesota Building Code.

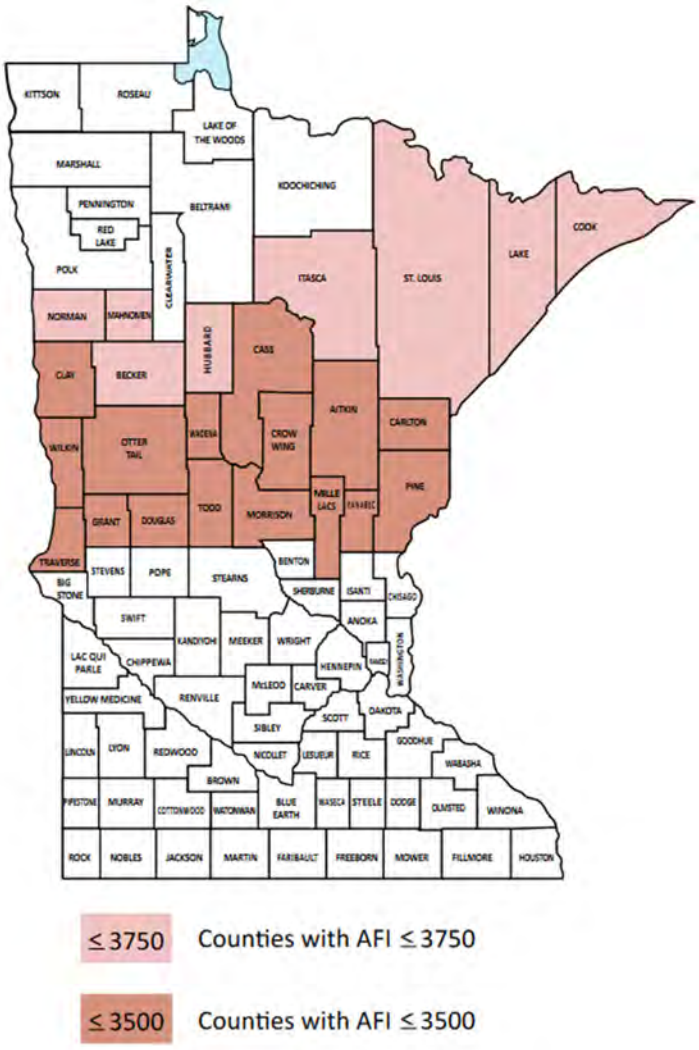

Figure 42. Map of Air Freezing Index in Minnesota Counties
Note: *Frost protected foundations for northern Minnesota*. (n.d.).

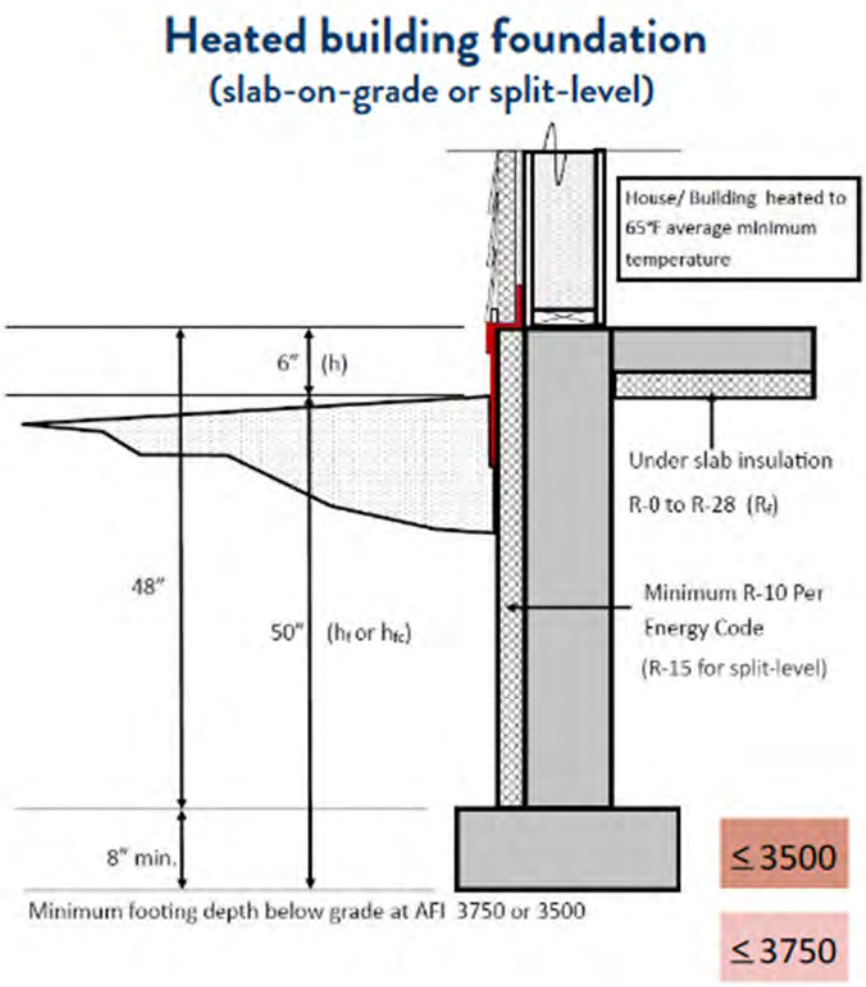

Figure 43. Example of an Approved Heated Building Foundation Detail
Note: *Frost protected foundations for northern Minnesota*. (n.d.).

Due to these requirements, the slab's depth shall be at least six inches, the R-value shall be between R-0 and R-28, the footing shall be at least 50" below grade, and the bottom of the footing shall have a minimum thickness of 8".

3.3.3. Wall Construction

The walls shall be constructed using prefabricated panelized construction. The 4' x 8' panels will be a double-stud wall using 2" x 4" wood studs and 12" of hempcrete infill. The hempcrete infill will function as insulation. Hempcrete material costs between "$5.25-$6.75 per cubic foot of material after installation" (*Building A Hempcrete Home: Say Goodbye To Classic*

Concrete - The Tiny Life, n.d.). 2” x 4” x 8’ studs are estimated to be $3.34 per stud (*2x4 - Framing Studs - Dimensional Lumber*, n.d.). Exterior walls will have an interior lime plaster finish and engineered wood siding. Interior walls will use a gypsum wallboard finish to help save on costs as a breathable wall material is not required for an uninsulated wall. Installing gypsum wallboard “costs between $1.50 and $3 per square foot” (*Learn How Much It Costs to Apply Plaster.*, n.d.).

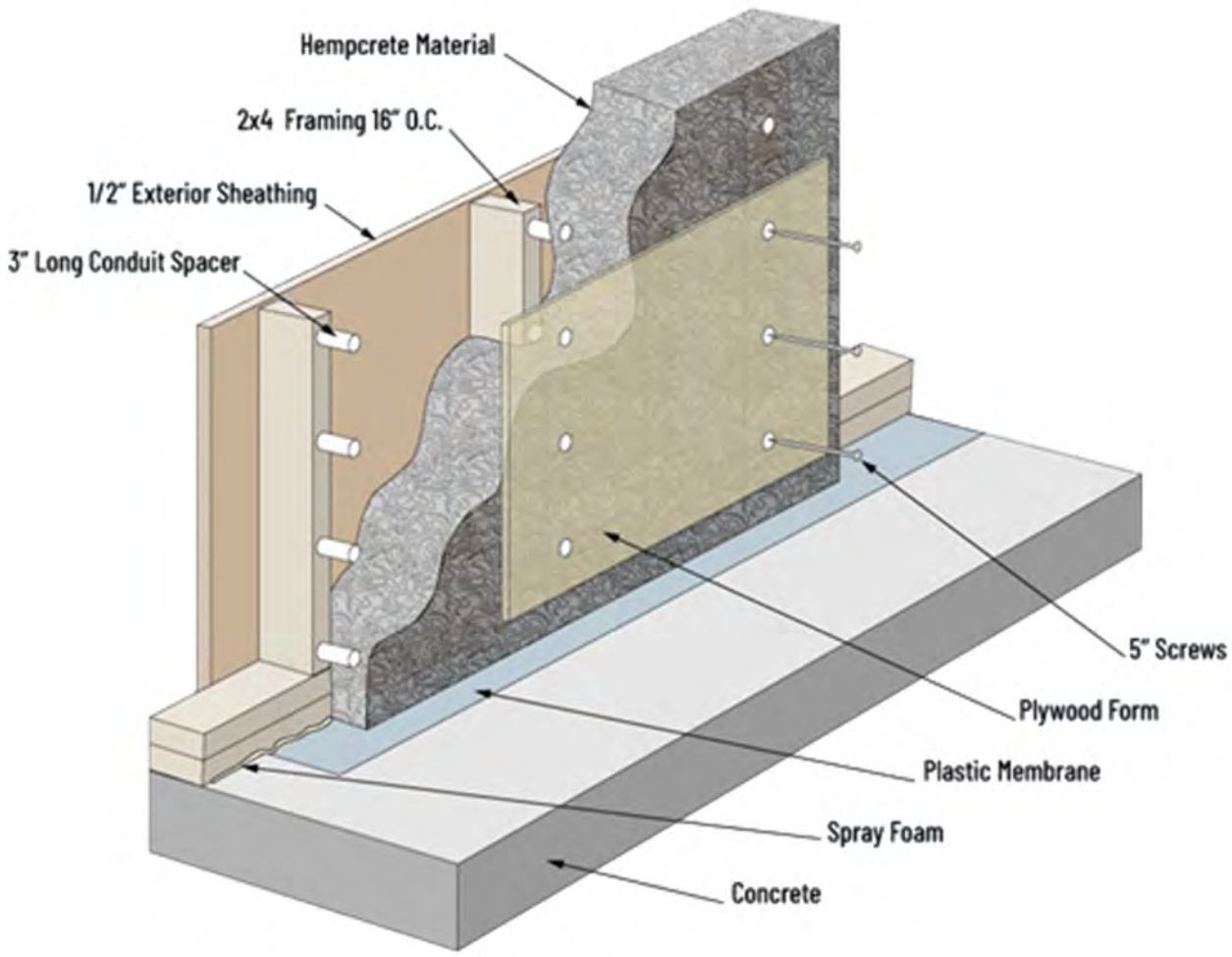

Figure 44. Hempcrete Wall Construction
Note: Hempcrete-wall-composition.jpg (JPEG Image, 1000 × 731 pixels). (n.d.). Retrieved November 1, 2023, from https://thetinylife.com/wp-content/uploads/2023/07/hempcrete-wall-composition.jpg

Figure 45. Frame on Center Hempcrete Wall Construction
Note: Hempitecture. (2020, May 5). Hempcrete Wall Detailing. Hempitecture Inc. https://www.hempitecture.com/post/hempcrete-wall-detailing

3.4. Cost Analysis

The following prices are rough estimates gathered from various sources. The price estimates were created by taking the median average cost per square foot or cubic foot and multiplying it by the amount of material within the project. These estimates may vary either higher or lower depending on the estimate given by the manufacturer and or contractor.

BUILDING COMPONENT TYPE	EST. AMOUNT OF MATERIALS			EST. COST MATERIALS		
	AREA (SF)	VOLUME (CF)	NUMBER	PER/SQFT	PER/CF	PER/#
Monolithic Slab on Grade Foundation	3911			$5.00		
Gypsum Wall Board on Interiors	5537.12					
Plaster Wall	3183.32			$10.00		
Engineered Wood Siding	3183.32			$6.08		
Hempcrete Insulation		3155			$6	
Double Stud Wall (2x4 Wood Studs)			872			$3.35
Fenestration (Double Pane, Low-E, Glazing	1220		92	$12		
Green Roof	4822			$15		

BUILDING COMPONENT TYPE	EST. COST INSTALLATION			TOTAL MATERIAL	ROUGH EST. TOTAL	ROUGH EST. TOTAL
	PER/SQFT	PER/CF	PER/#			
Monolithic Slab on Grade Foundation	$4			$19,555.00	$15,644.00	$35,199.00
Gypsum Wall Board on Interiors	$2.25			$0.00	$12,458.52	$12,458.52
Plaster Wall	Installation cost included in material cost			$31,833.20		$31,833.20
Engineered Wood Siding	Installation cost included in material cost			$19,354.59		$19,354.59
Hempcrete Insulation	Installation cost included in material cost			$18,930.00		$18,930.00
Double Stud Wall (2x4 Wood Studs)	Prefabricated Framed Wall			$2,921.20		$2,921.20
Fenestration (Double Pane, Low-E, Glazing)			$900	$14,640.00	$82,800.00	$97,440.00
Green Roof	$7.50			$72,330.00	$36,165.00	$108,495.00
						$326,631.51

Figure 46. Cost Estimate

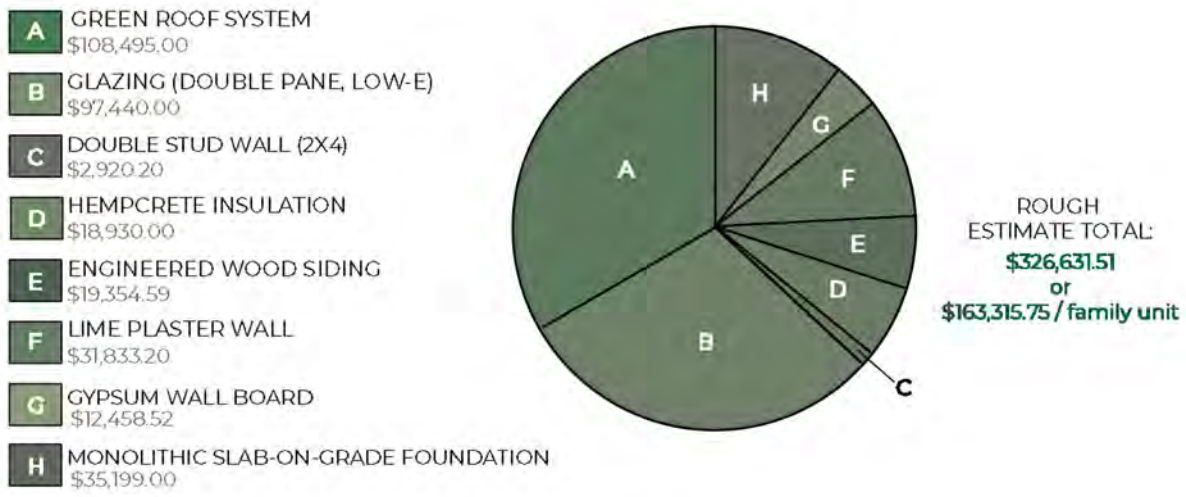

Figure 47. Cost Estimate

3.5. Inspiration

Figure 48. Inspiration
Note: modern-country-home-architecture-230121-1213-02.jpg (JPEG Image, 1913 × 2560 pixels)—Scaled (35%). (n.d.). Retrieved November 2, 2023, from https://www.contemporist.com/wp-content/uploads/2021/01/modern-country-home-architecture-230121-1213-02.jpg

Figure 49. Modern Hemp House
Note: The house that hemp made: Steve Barron on his house at Margent Farm. (2021, May 21). https://www.themodernhouse.com/journal/margent-farm-steve-barron-practice-architecture/

Figure 50. Modern Hemp House
Note: The house that hemp made: Steve Barron on his house at Margent Farm. (2021, May 21). https://www.themodernhouse.com/journal/margent-farm-steve-barron-practice-architecture/

Figure 51. Staggered Kindergarten
Note: Gallery of Kindergarten over the Vineyard / architekti.sk—2. (n.d.). ArchDaily. Retrieved December 4, 2023, from https://www.archdaily.com/771672/kindergarten-over-the-vineyard-architektk/55c95468e58ece5c7d000225-kindergarten-over-the-vineyard-architektk-photo

Figure 52. Staggered Kindergarten
Note: Gallery of Kindergarten over the Vineyard / architekti.sk—2. (n.d.). ArchDaily. Retrieved December 4, 2023, from https://www.archdaily.com/771672/kindergarten-over-the-vineyard-architektk/55c95468e58ece5c7d000225-kindergarten-over-the-vineyard-architektk-photo

Figure 53. Roof Window Cooperative Housing
Note: full_Velux_Group_Roof_Window_on_Cooperative_in_Erdeven_France_-_13.jpg (WEBP Image, 1024 × 683 pixels). (n.d.). Retrieved December 4, 2023, from https://snoopy.archdaily.com/images/archdaily/catalog/uploads/photo/image/306534/full_Velux_Group_Roof_Window_on_Cooperative_in_Erdeven_France_-_13.jpg?width=1024&format=webp

Figure 54. Prefab Passive House
Note: (JPEG Image, 876 × 516 pixels). (n.d.). Retrieved December 4, 2023, from https://cdnassets.hw.net/dims4/GG/0effefc/2147483647/resize/876x%3E/quality/90/?url=https%3A%2F%2Fcdnassets.hw.net%2F95%2F4d%2F152f58784650a31976a31c82d008%2Ftmpe6-2etmp-tcm20-1969321.jpg

Figure 55. Tiny Victories 2.0 by Chioco Design
Note: original.jpg (AVIF Image, 1600 × 2000 pixels)—Scaled (45%). (n.d.). Retrieved December 4, 2023, from https://images2.dwell.com/

Figure 56. Tiny Victories 2.0 by Chioco Design
Note: original.jpg (AVIF Image, 1600 × 2000 pixels)—Scaled (45%). (n.d.). Retrieved December 4, 2023, from https://images2.dwell.com/photos/6818593201364905984/6862860915595681792/original.jpg?auto=format&q=35&w=1600

Figure 57. Tiny Victories 2.0 by Chioco Design
Note: *original.jpg (AVIF Image, 1600 × 2000 pixels)—Scaled (45%)*. (n.d.). Retrieved December 5, 2023, from https://images2.dwell.com/photos/6667108702194143232/6846915388062892032/original.jpg?auto=format&q=35&w=1600

Figure 58. Modular House Cupa Pizarra
Note: Full_4 (WEBP Image, 1024 × 640 pixels). (n.d.). Retrieved December 4, 2023, from https://snoopy.archdaily.com/images/archdaily/catalog/uploads/photo/image/115814/full_4?width=1024&format=webp

Figure 59. Modular House Cupa Pizarra
Note: Gallery of Natural Slate in Modular Housing—5. (n.d.). ArchDaily. Retrieved December 4, 2023, from https://www.archdaily.com/catalog/us/products/12314/natural-slate-in-modular-housing-cupa-pizarras/115817

Figure 60. Modular House Cupa Pizarra
Note: Gallery of Natural Slate in Modular Housing—5. (n.d.). ArchDaily. Retrieved December 4, 2023, from https://www.archdaily.com/catalog/us/products/12314/natural-slate-in-modular-housing-cupa-pizarras/115817

Figure 61. Attractive Low-Cost Housing
Note: Attractive low-cost housing. (n.d.). Retrieved December 4, 2023, from https://vandkunsten.com/en/projects/almenbolig-danmarksgrunden

Figure 62. Overhead Photo of a Development
Note: CP_Overhead_2012WEB-2-1.jpg (JPEG Image, 600 × 406 pixels). (n.d.). Retrieved December 4, 2023, from https://www.eahhousing.org/wp-content/uploads/2017/09/CP_Overhead_2012WEB-2-1.jpg

4. RESULTS AND CONCLUSIONS

4.1. Project Description

The final project is an affordable housing development located in upper Duluth, MN. There are a total of 16 dwellings on the site, each dwelling uses the same floor plan. The development includes shared pathways that help connect the various parts of the development together to create more community spaces for residents. The development also includes shared parking lots between dwellings, as well as roadways that follow the natural topography lines of the site.

The floor plan of each dwelling consists of 1,200 square feet and includes two bedrooms and a bathroom, shared patio spaces, and a shared wall to help lower the cost of plumbing, materials, and to help prevent heating and cooling loss. The repetition of the same floor plan helps to keep the cost of the project low.

The dwellings use a prefabricated modular wall system made with natural materials (hempcrete, timber, engineered wood siding, lime plaster), as well as monolithic concrete slab-on-grade foundation. A green roof system is utilized which helps to promote wellness and sustainability on the site.

4.2. Project Objective

To meet the objective of designing an affordable housing development that integrated healthy building materials and sustainability, I researched various building materials/products, weighed the positives and negatives of each, and chose materials based off price as well as health benefits and recyclability. After determining the materials that would be used, I calculated the amount of each material in the dwelling and multiplied it by the median price of that product. This allowed me to determine if those materials could be integrated into affordable housing. I specified the healthy building materials in my project by using details to illustrate where the materials would be used. I also included sustainable practices like thermal mass, and solar heat gain on the south side of each dwelling.

4.3. Project Design and Documentation

This section includes the final design for this architectural thesis project.

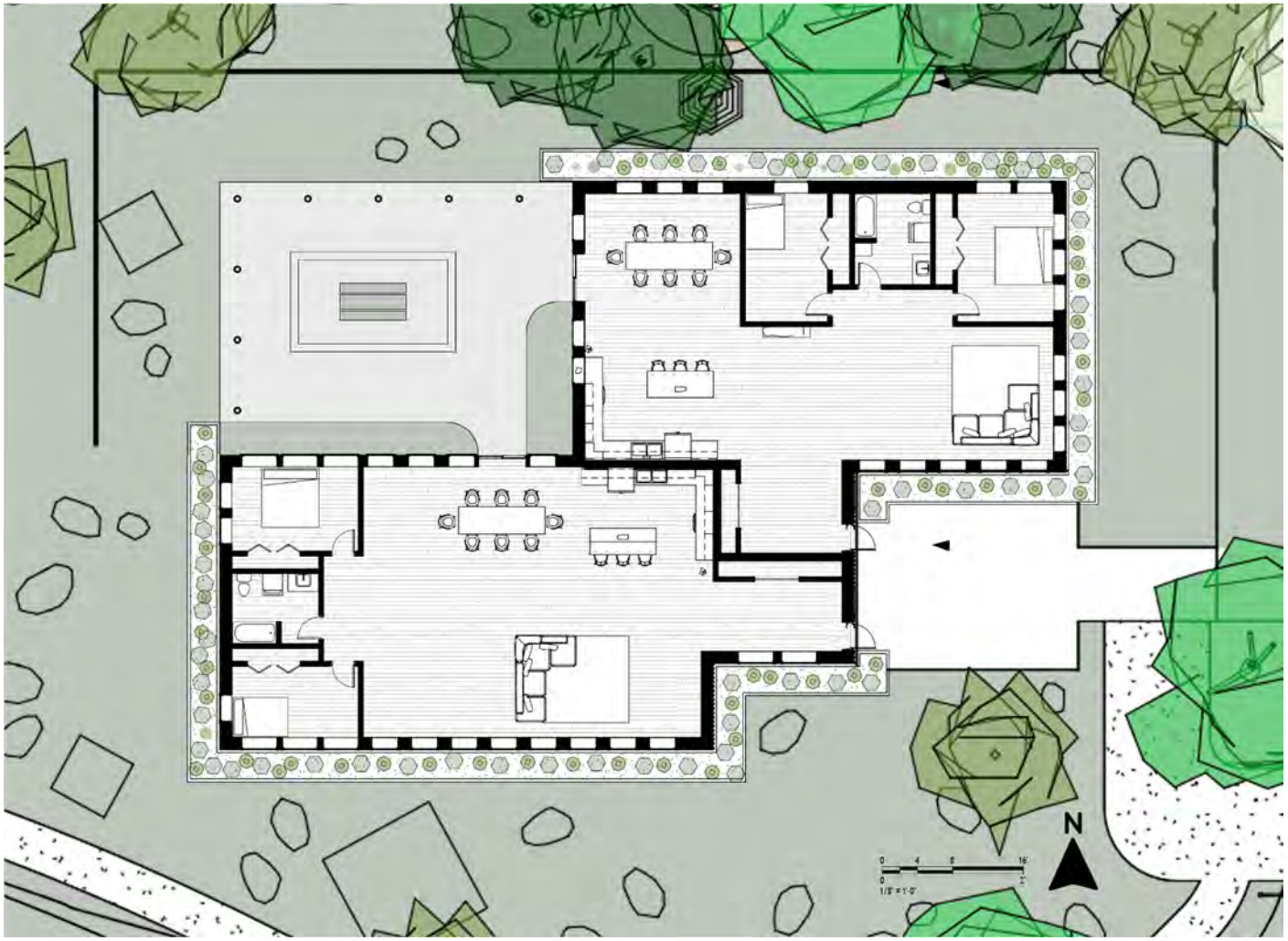

Figure 63 Floor Plan

Figure 64. Site Plan

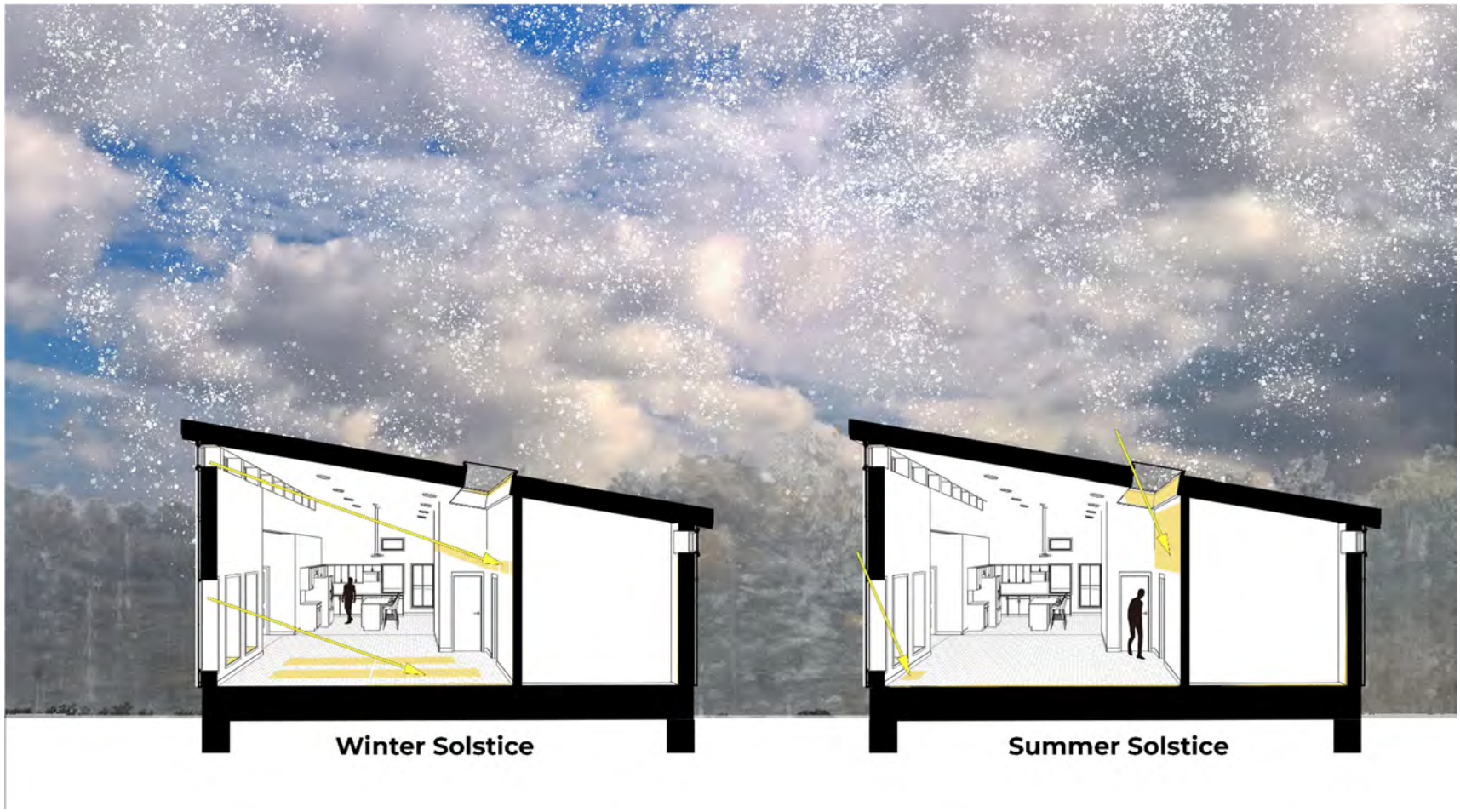

Figure 65. Section Perspectives

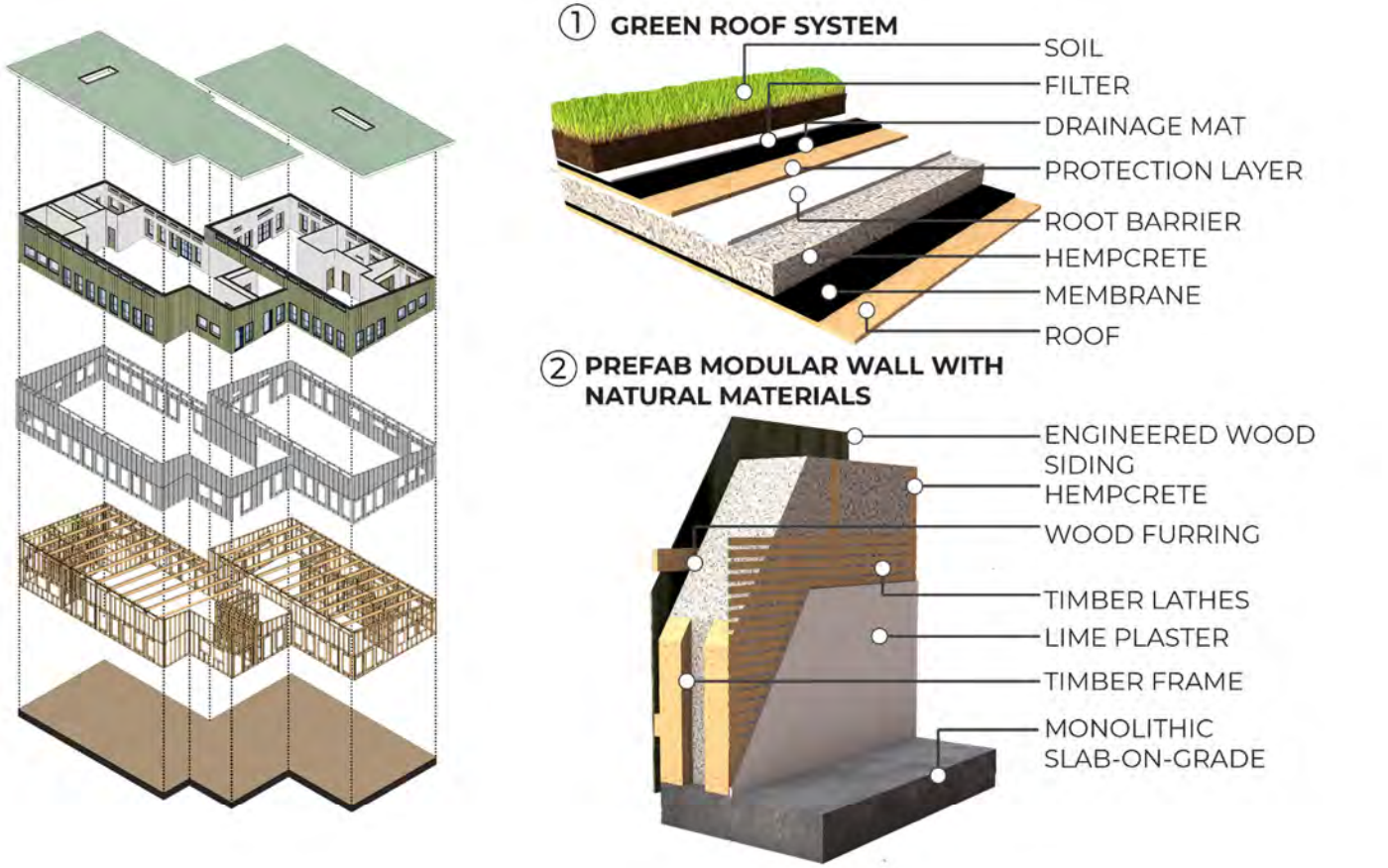

Figure 66. Exploded Axonometric, 3D Roof Detail, and 3D Wall Detail

Figure 67. Dwelling Exterior

Figure 68. Dwelling Interior

Figure 69. Dwelling Interior

Figure 70. Outdoor Space

Figure 71. Outdoor Space

Figure 72. Thesis Board

Figure 73. Thesis Board

4.3.1. Hempcrete Wall

During winter break, I got into contact with Matt Marino at Homeland Hempcrete in Bismarck, ND and constructed a small hempcrete wall. Prior to packing the wall with the hempcrete, Matt constructed the frame of the wall using 2x4 wood studs which were spaced 16" on center. The frame also contains horizontal bracing which he explained would be in a typical wall panel. This wall panel is 7-1/4" thick.

Figure 74. Wood Stud Wall

To begin, Matt measured out 25 pounds of water and about eight to nine pounds of lime. He then used a hand mixer to mix the two together. After the water-lime solution was formed, he measured out nine pounds of hemp shiv and divided the measured hemp shiv into two separate containers. Next, he poured half the water-lime solution into each container. The

water-lime solution acts as a glue that binds the hemp shiv together. After pouring the glue-like mixture in, we began to hand mix.

Figure 75. Hemp Shiv

After the hemp shiv, water, and lime were combined, I began to pack it into the wood stud wall. We used a slip form to help shape the hempcrete as it was packed into the wall. After packing the hempcrete up to the top of the slip form, we moved it up and continued the packing process. We used about three batches of hempcrete to pack the wall, which took about an hour.

Figure 76. Partially Packed Hemp Wall

After the wall was packed, Matt put plastic around it to help some of the water to evaporate. The plastic was left on for 72 hours and then removed along with the formwork. Matt informed me that once the wall is completely cured, it weighs about 60% less than its original weight. The curing process is estimated to take about four weeks.

Figure 77. Finished Hempcrete Wall in Formwork

4.4. Conclusion

In conclusion, it is possible to integrate sustainability into affordable housing, and it can be done by specifying better material and bringing more awareness to materials that might not be used as often, reaching out to various funding sources and grant programs, and finally by looking at different construction processes that can help save money in a project so that that money can be spent elsewhere. Hempcrete is a great material that provides good indoor air quality and takes a tremendous amount of carbon dioxide out of the environment. Overall, it is important to create housing that is livable and provides healthy environments for people to grow and connect.

A few items I overlooked during this process were the HVAC systems, plumbing, and electrical costs. These systems would need further investigation to obtain a more accurate cost estimate. A ground source hear pump was recommended during critiques, as there is a good opportunity for multiple dwellings to share one system. The investigation of other materials is encouraged as well, as there are other healthy building products available. Architects and designers should remain aware of new materials or processes that continue to be introduced, as things are constantly changing, and it is important to stay up to date in the construction industry.

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APPENDIX A. PREVIOUS STUDIO EXPERIENCE

YEAR	SEMESTER	PROFESSOR	PROJECTS
2nd	Fall: 2020	Charlott Greub	Land Art Artist Studio / Minneapolis Boathouse
	Spring: 2021	Cindy Urness	Marfa Dwelling / Boutique Hotel
3rd	Fall: 2021	Paul Gleye	Mixed-Use Center for Students / Pella Windows
	Spring: 2022	Whitney Lee	Native American Cultural Center / Fargo Veteran's Cemetery Competition
4th	Fall: 2022	Roland Sharpe-Flores	Capital Community Apartments (Capstone)
	Spring: 2023	Kristi Hanson	Marvin Windows Competition / Imagining Minot
5th	Fall: 2023	Regin Schwaen	Thesis / The Legendary Highway Tower 14
	Spring: 2024	Regin Schwaen	Healthier Homes (Thesis)