EMBODIED ENVIRONMENTAL IMPACT

D8 SUBMISSION

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US DEPARTMENT OF ENERGY SOLAR DECATHLON BUILD CHALLENGE

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I. Design

The design philosophy of the home was to use building materials and construction methods that could be sourced locally, creating a strong sourcing dependence on the local businesses, and supporting them. If compared to a standard home, the embodied environmental impact of the Wind River home would be on a lower end because of our ideology to not use any material not locally available. This made us secure several materials that are abundant in Wyoming and added a lot of indigenous characteristics to our design.

a. Foundation

The concrete slab-on-grade foundation is an unavoidable carbon intensive material. A typical house will have this system as the foundation and any additionally required footers. While there are different types of foundation systems that are in development and can be implemented, the goal of this home was to facilitate the ease of buildability, so that it could be replicated by any general contractor in and around the region. It is common for the concrete slab to be topped with a flooring material. However, the home has radiant in-floor heating which requires the flooring material to be a heat conductor. These materials are typically tile, however our team chose to simply polish and finish the concrete slab to eliminate the need for additional flooring material. By duplicating the use of the concrete slab as the foundation and the flooring material, heat can be directly transferred into the space and provides construction cost savings. This also provides a lot of customizability for the future homeowner. Obviously, it would be our team's preference for the homeowner to keep the concrete floor, but if there comes a time that they would prefer a tile that can be easily added.

b. Walls

Standard stick and frame construction is typically a carbon neutral structure, meaning this material will absorb as much carbon as it emits. This type of construction also requires very little use of heavy equipment and a small amount of transportation as often the timber is sourced locally.

Insulation is another material in the home design that carbon emissions had to be sacrificed for the overall efficiency of the other home systems. This material is considered a high emitting material because it requires the extraction of materials from the earth and intense processes to then take the extracted materials and turn them into insulation. The type of insulation that the ZIP system uses is made of polyol, fire retardant, blowing agent and methylene diphenyl diisocyanato (MDI). Polyol is an organic material made of multiple hydroxyl groups. In the spray foam insulation that is used in the rest of the wall

cavities, the spray foam insulation is made using isocyanate and polyol resin. Isocyanate is an organic compound as well and is a simpler compound than the MDI system mentioned earlier. Although some of these components are organic compounds, the processes to make these chemicals are intensive in terms of carbon emissions.

c. Finishes

Finished steel panels are used as the main exterior siding and roofing material. While the process to make steel is extremely carbon intensive, the steel industry makes efficient use of recycled steel. Once steel is made, it can be continuously melted down and reformed. During the use of the steel, it is a very durable material and will require very little maintenance by the future homeowner. This is why this was an ideal material to use as the main material. At the end of this material's 40-to-70-year lifespan it can be easily recycled and replaced quickly. This is compared to a typical asphalt roof which only has an expected lifespan of 12 to 20 years and requires maintenance throughout because it is easily damaged.

From an architectural aspect, a home fully covered in steel siding can feel cold and uninviting, so a second material was sought after. The use of the reclaimed snow fence was a low emitting material that could aesthetically make the home more welcoming and inviting. A snow fence (figure 1), is typically an angled wooden fence that forces snow to drift into a desired location. These are found across Wyoming especially near busy highways and other roadways. Unfortunately, because of the heavy winter conditions in these areas, the snow fences require yearly maintenance to continue to be effective and tend to have a short lifespan. The Wyoming Department of Transportation (WYDOT) will harvest these worn pieces of 2x4 and sell them to local lumberyards. Weathered wood is "in style" currently and creates the ideal aesthetic appeal for our home. The repurpose of this material reduces the need for virgin material to be used as siding for the home. If the need for replacement ever arises, this local material would be easy to source and reinstall with minimal waste.

Another common aspect in every home is gypsum wallboard. While the process to mine and create this material is carbon intensive, it is an expectation of homebuyers and a standard in all homes. This home will be sold once construction is complete and excluding this material could deter many potential buyers.

Casework throughout the home is also a standard in any home and is being locally sourced and constructed. This increases the customizability of the architecture team and reduces the transportation emissions. Staying local with this aspect also supports our design philosophy and engages the community in the project.

d. Other

The windows are another aspect of this design which are locally sourced and require very little transportation. Copper plumbing is another aspect of this design that can be recycled once finished and can be locally sourced.

Figure 1: Wyoming snow fence, used to create drifts next to roadways.

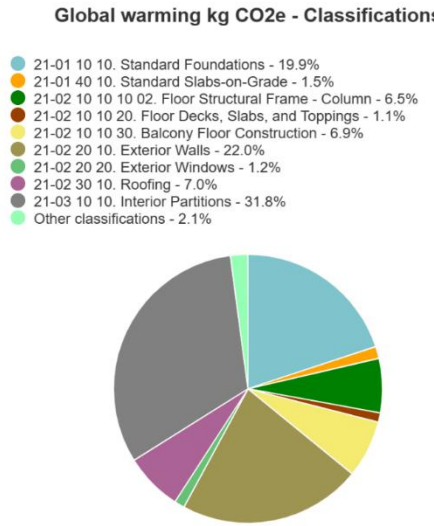

Figure 2. Global Warming Potential Based on Material Groups.

II. Embodied Environmental Impact

With growing concerns of global warming, all construction fields have begun using embodied carbon as a factor in material choices and design decisions. The best way to calculate this is conducting a full life cycle assessment (LCA). These assessments are based on environmental product declarations (EPDs) issued by the manufacturers of specific products. These EPDs can look at up to five stages of a product:

Stage A1-A3: Product Manufacturing

Stage A4-A5: Construction

Stage B1-B5: Product Use (including maintenance, repair, and replacement)

Stage C1-C4: Product End of Life

Stage D: Product Reuse-Recovery Recycling Potential

These EPDs calculate the embodied carbon in kg CO2e/ton or other standard measurement, so the weight of each of the material is calculated using the LCA. Many EPDs are related to non-US countries because currently, EPDs are not mandated by any regulatory agencies. Because of this, in conducting an LCA it is imperative to understand how materials are manufactured and how processes can change depending on what country the product is manufactured in. Although some US companies have voluntarily gone through this process typically because it is a part of their company's mission to be more sustainable.

Table 1. Breakdown of Life Cycle Stages

A1–A3 Materials	200,000 kg CO_2e	84.99 %
A4 Transport	8,900 kg CO_2e	3.70%
A5 Construction	20,000 kg CO_2e	8.38 %
B4–B5 Replacement	2,300 kg CO_2e	0.95 %
C2 Waste transport	2,200 kg CO_2e	0.91 %
C3 Waste processing	2,600 kg CO_2e	1.07 %

One Click LCA is a plug-in application to REVIT which will import the materials already assigned in the model. This was ideal for a cohesive analysis and ensures that all materials are reflected accurately. When conducting this LCA, when a US EPD was not available, a Canadian EPD was substituted. Canada has similar manufacturing processes in most of the materials used to build this home and are typically considered "North American" products.

Using One-Click LCA, the total embodied carbon was calculated to be approximately 240 tons of CO_2e for all stages of the Life Cycle assessment, each stage is broken down in **Table 1.** Breakdown of Life Cycle Stages. The highest emitting stage is the construction and manufacturing of the products with 85% of the total embodied Carbon, followed by the construction. With any product, this is the most carbon intensive process of the LCA. As seen **Error! Reference source not found.**, most of this total embodied carbon comes from the exterior walls. This is due to the high environmental impact of the insulation used in the ZIP system. Again, this was a sacrifice our team willingly made for overall efficiency of the design. The second highest emitter was the foundation system, which is logical because the process to make concrete is extremely carbon intensive.

Figure 3. Reclaimed snow fence, Centennial Woods

Figure 4: Reclaimed snow fence siding being installed at Wind River home.

III. Life Cycle Assessment

This home uses the best technology locally available, but not every home has these technologies. If this home was not intentionally built with all the technical component, the embodied carbon would look very different, just because of the amount of energy required to run essential functions of the home. For example, the addition of radiant in-floor heating saves the future homeowner between 15 and 25% on their heating system [1]. Another addition is the extra insulation that also helps to reduce the overall heating and cooling loads. These are additional costs and additional carbon emissions but add to the overall strength of the heat.

IV. Net Carbon

An important aspect of any carbon analysis is the upfront versus operational carbon. Upfront carbon is all from the construction of the building and as seen in both Table 1 and Table 2 most of the carbon exchange comes from the construction of the building and the end of life of the material. The operational carbon of the home is extremely low. This is because the selection of the home's MEP systems and any additional carbon will be dependent on the future homebuyer's lifestyle. The net carbon of just the construction shows the balance of the carbon emissions being released and the carbon emissions being stored. Again, following the trend of the upfront carbon being the most intensive versus the operational carbon.

Table 2. Net Carbon Analysis Results Summary

A1-A3 Material	-74, 000 kg CO_2e	18.77%
A4 Transport	6,100 kg CO_2e	-1.53%
A5 Building Site	-24, 000 kg CO_2e	6.09%
B4-B5 Replacement	2, 200 kg CO_2e	-0.54%
C2 Waste Transport	2, 200 kg CO_2e	-0.55%
C3 Waste Processing	2,600 kg CO_2e	-0.64%
D External	-310, 000 kg CO_2e	78.42%

This recyclability is further supported by the building circulatory assessment which resulted in 100% of materials being returned, as seen in **Figure 5.** Summary of Building Circulatory Results.

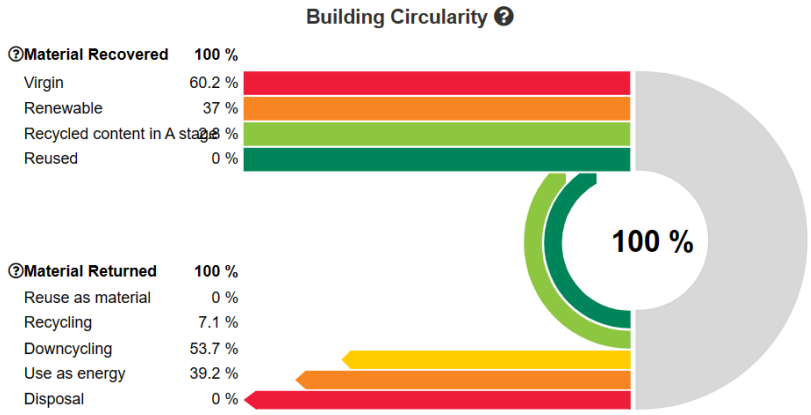

Figure 5. Summary of Building Circulatory Results.

V. Avoided Emissions

Regarding operational energy, we examined the avoided emissions of the Wind River house. Finding data about residential energy use is difficult. Using a variety of sources and tools, we have concluded that the typical Wyoming house uses, annually:

- 29,817 kWh of natural gas
- 27,166 kWh of electricity
  Note: In Lander, Wyoming (High Plains Power), electricity is produced by:
  - Coal: 40%
  - Gas: 23%
  - Hydro: 9%
  - Wind: 25%
  - Solar: 3%

Therefore, the avoided emissions per year are:

- 7,439 kg CO_2 from avoiding natural gas
- 14,243 kg CO_2 from avoiding utility-supplied electricity
- **21,682 kg CO_2 total**

Note: carbon savings from driving EVs instead of gasoline-powered vehicles are not included but would also be profound.

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VI. Innovation

Every aspect of the design was designed to keep the embodied carbon low but to also keep in mind overall design efficiency. Each material can be locally sourced and transported to the site, which when considering the emissions and knowledgeable labor is a big advantage. Reusing the concrete floor as the finished flooring to reduce cost, emissions and improve heat gain and attract future homeowners is a great innovation of that is also a popular trend right now.

Another strong innovation is the use of each of the materials in their rawest state before modification. This is also a part of the marketing as a minimalist mountain modern home. This rawness of material encourages the future homeowners and anyone who visits the home to appreciate the beauty of the materials as is. Because of the rawness of the materials, they are easily recyclable or reusable if replacement was ever needed.

References

1. Nesbit, J. (2022, May 31). *Radiant heat in your home: Is it worth it? - US news & world report*. U.S. News. Retrieved March 27, 2023, from https://realestate.usnews.com/real-estate/articles/radiant-heat-in-your-home-is-it-worth-it