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Intergenerational Affordable and Energy-Efficient Multifamily Housing Proposal for Bowen Island's Young to Senior Population.

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Abstract

This thesis addresses an intergenerational multifamily housing proposal with energy-efficient, sustainable, and affordable housing solutions on Bowen Island, Vancouver. The importance of this topic lies in the necessity to balance environmental responsibility with the socio-economic realities of housing accessibility. Bowen Island, with its particular population demographics and environmental context, serves as the focal point for this study. One of the main objectives of this thesis is to find an affordable housing solution for the needed population, including young, post-parental families, empty nesters, and elderly people.

The initial part of the thesis outlines the research objective of developing a multifamily housing proposal that integrates energy-efficient and sustainable strategies while being affordable for a specific segment of the island's population. This chapter is divided into three main parts. First, it explores the concepts of sustainability, energy efficiency, and affordability applied to housing development. The second part seeks to understand these concepts through different case studies and research into housing needs for future reference and development in the thesis. Finally, it investigates palafitic architectural case studies that will help with the development of the project in sensitive environmental areas such as Bowen Island.

Following this analysis, the thesis dives into the project context by understanding demographic trends, historical timelines, policy initiatives, and interviewing current residents on Bowen Island. This will provide a clear image of the housing necessities on the island and serve as a tool to propose future housing solutions for young, post-parental families and the elderly population. Moreover, it is important to understand the characteristics of the specific site of the project and its service requirements.

The second part of the project highlights the formulation of the proposal. It emphasizes integrating energy-efficient and sustainable strategies into the design process to ensure environmental responsibility and affordability. Additionally, it provides an explanation of the proposal from a master plan scale and a specific scale, understanding how the houses will be built.

Moving forward, the project evaluation explains the building performance of the proposed housing project, assessing energy, social, and economic metrics. By analyzing energy performance alongside social and economic factors, the thesis aims to demonstrate the integrated benefits of energy-efficient and sustainable housing solutions in an affordable project.

In conclusion, this thesis proposes an environmentally conscious and affordable approach to addressing the housing challenges on Bowen Island, integrating energy efficiency, sustainability, and affordability. Through the different investigations and analyses conducted in the thesis, the proposed housing project seeks to serve as a model for future development, prioritizing the well-being of the island's population and the planet.

Introduction

Due to the current affordability issue occurring in Bowen Island, Canada, there is an urgent need to generate housing solutions for the residents that addresses the financial constraints that have been growing through the years. The growth of the property values and the living costs have generated a displacement from the island of the low- and medium-income families, as long as they can't find affordable housing options to continue living there.

In addition, considering the importance of long-term viability and the climate situation in Bowen Island, by integrating energy efficient strategies into the house design, it ensures a prolonged economic benefit for the residents. Also, it helps with reducing the utility/bills costs and also the community integration.

Certainly, Bowen Island has a demographic diversity, which includes the long-term residents, the young people, the retirees and the Island workers. This has generated an important social framework that leads to the inclusivity and community initiatives. Nowadays, the municipality involves the residents in the decision-making processes through diverse committees, meetings and public consultations guiding to an ownership of the island. Besides, in order to address the diverse needs of the population, there are different support services, accessibilities, cultural events, social inclusion activities and affordable housing initiatives in relation to the main problem occurring on the island.

Moreover, the island is well connected to Vancouver, which allows the island residents to have a convenient residential choice if they work in the city and want a calmer living space. Also, the visitors can travel easily to and from Vancouver, making Bowen Island accessible and an attractive residential option.

This way, throughout this thesis we want to mitigate the community displacement and generate a cost-effective living space for the actual and future residents of Bowen Island. The objective is to create a more inclusive housing project, emphasizing the significant population changes and desirable location, reducing the environmental footprint of the new constructions and utility costs for the residents, and generating a long-term sustainability project that leads to a high-quality life for them.

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Housing design considerations

1 Project focus

1.1 General objectives

Design an affordable and energy efficient intergenerational multifamily housing proposal in Bowen Island, that integrates the sustainability principles, affordability needings and communitary cohesion, answering to the diverse demographic groups needings and the environmental requirements of the island.

1.2 Specific Objectives

- Evaluate the application of affordable, energy efficient and palafitical architecture case studies on housing projects.

- Analize the demographic trends and migration in Bowen Island and its impact on affordable housing demand

- Evaluate the viability of a multifamily housing design for different age groups through strategies of urban planification, renewable energy and sustainability, adapted to the specific conditions of the lot and the residents affordable needs.

- Purpose a master plan that integrates houses adpated for diferent generation groups with specific flexible typologies, that combine energy efficience strategies and reduce the initial and living costs for the residents.

- Design specific houses for the population target that answer to their space and economic needs

- Implement energy efificient and sustainable startegies on the houses in order to maximize the house performance and the adaptation to Bowen Island evironmental situation.

- Evaluate the energy performance of the houses through indicators of energy efficiency and consumption and building envelope and comfort, considering the international sustainability standards.

- Measure the social impact of the project in relation lo life quality of the residents and the community interaction, that promotes a social cohesive environment.

- Demonstrate the affordability of the project through initial and operational costs and ong term benefits, that ensures the economic sustainability.

1.3 Problem question

How can a multifamily housing design on Bowen Island, address the changing needs of a diverse age population while maintaining affordability and energy efficiency?

2 Theoretical framework

2.1 Sustainability applied in housing proposals

The sustainability applied in housing proposals, especially in a multifamily housing proposal for an intergenerational community, has to be addressed from an integrated perspective, incorporating environmental, social, economic and institutional aspects. This allows the houses to respond to both current needs of the inhabitants and to contribute to the welfare and social community cohesion in the long term. According to the Housing Sustainability Assessment Tool (HSAT), a tool that assesses sustainability in housing development based on the United Nations Geneva Charter on Sustainable Housing, an integral proposal must include these principles to maximize its positive impact (Adamec, Janoušková, & Hák, 2021).

Balance of Sustainability Dimensions
A fundamental sustainability component in housing is the balance between the environmental, social, economic and institutional dimensions. This balance ensures the livability and affordability of the houses and drives a consistent development that integrates the natural and communitary aspects of a project (Adamec, Janoušková, & Hák, 2021). For Bowen Island project, this balanced approach is reflected on the housing construction that optimize resource usage, minimize the environmental impact and foment the interaction between the diverse age population community. This model should imply the use of local materials that reduce the carbon footprint, the development of flexible housing units that answer to the changing needs of the residents and the creation of common spaces to facilitate the community meeting.

Integral evaluation and sustainability indicators application
The use of specific indicators is fundamental to measure and guarantee the sustainability in a housing proposal. In the HSAT case, the indicators evaluate from energy consumption and water efficient usage to social aspects such as community cohesion and citizen participation. This extensive evaluation allows to monitorate the environmental and social impact of the houses in the long term, ensuring that they remain affordable and sustainable (Adamec, Janoušková, & Hák, 2021). In Bowen Island context, these indicators can be applied to verify the accomplishment of specific objectives, such as the annual energy efficiency of each unit, the reduction of the carbon footprint through the use of renewable energies and the accessibility to common spaces. In this way, the use of an indicator system helps to structure the housing proposal to comply with the international sustainability standards and allows to realize adjustments according to the community needs (Adamec, Janoušková, & Hák, 2021).

Reduction of environmental impact and energy efficiency
A central aspect of sustainability in housing is the minimization of the environmental impact. This implies not only constructing houses that reduce the energy and water consumption, but also designing structures that can adapt into the natural environment of Bowen Island. Energy efficiency can be achieved by passive design strategies, such as solar orientation and thermal insulation, that helps to reduce the dependence on heating and cooling systems, benefiting both environment and the residents through lower energy costs (Adamec, Janoušková, & Hák, 2021). Also, the implementation of rainwater harvesting systems, solar panels and low environmental impact materials as the wood, accessible locally and provides thermal insulation. These strategies not only contribute to the project sustainability but also reinforce the resilience to climatic change, an important factor for any development on vulnerable or ecologic sensible areas, such as Bowen Island (Adamec, Janoušková, & Hák, 2021).

Social inclusion and community welfare
The creation of communities that creates social inclusion and welfare are essential in a housing intergenerational proposal. According to the principles of the HSAT, the design of well-planned common spaces and the active participation of the residents are indispensable to strengthen the sense of community and belonging (Adamec, Janoušková, & Hák, 2021). In an intergenerational context, the creation of spaces that invites the coexistence and exchange between young people and older adults, as community gardens or recreational areas, can reduce social isolation and generate an environment of common support. In the Bowen Island project, it's important to include shared spaces that facilitates the interaction between the different age populations, and that also reflects the sustainable values and the social cohesion.

Affordability and economic sustainability
Economic sustainability is key to guarantee that the dwellings are affordable in the long term. This implies the construction of affordable houses in terms of initial costs and maintenance, using resources and techniques that minimizes the operative costs (Adamec, Janoušková, & Hák, 2021). In Bowen Island, the incorporation of a modular and adaptable design allows the houses to adjust to the diverse residents life cycle, which helps the home stability and reduces the necessity of relocation or big renovations. The implementation of a flexible design allows residents to distribute their spaces as they need, a crucial aspect for a project that seeks to receive different generations. This not only improves the affordability, but also offers a sustainable solution that answers to the changing needs of the inhabitants (Adamec, Janoušková, & Hák, 2021).

In conclusion, applying sustainability principles in an intergenerational multifamily housing proposal in Bowen Island, not only creates an affordable and efficient housing model, but also foments the integration and belonging of the community. The HSAT provides a clear guide to structure the project in a way that it can integrate with its surroundings, and answers to the environmental and social needings, providing a sustainable development through long term.

2.2 Affordability applied on sustainability

Affordability in sustainable housing is an important factor in ensuring environmentally friendly homes are accessible to a broader population. Among the key factors to consider when it comes to affordability in sustainable housing are the building costs, energy efficiency of the building, community engagement, and maintenance costs.

In terms of initial costs, sustainable housing often involves higher upfront costs due to the use of eco-friendly materials and technologies. However, there are multiple financial incentives and figures that can make this practice possible. According to the U.S. Green Building Council, green buildings typically use 25% less energy and 11% less water, leading to significant savings over time (USGBC, 2022).

Energy efficiency also plays a crucial role in affordability. Energy-efficient homes reduce energy consumption and therefore lower the bills of the housing unit. The U.S. Department of Energy highlights that energy-efficient upgrades can save homeowners up to 30% on their energy bills (Energy Saver, 2024). Among the most important factors in energy consumption is the heating system of the building and its ability to heat the area without having any heat loss. This concept integrates two essential factors: the airtightness of the house and the HRV system.

On the other hand, community engagement in the planning and development process can lead to more affordable and sustainable housing solutions. This strategy ensures that the project meets the needs of the users. The World Green Building Council emphasizes the importance of community involvement in sustainable urban development (WorldGBC, 2024).

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Knowing this, it’s important to understand the long-term benefits in terms of affordability when it comes to sustainable strategies. While the initial costs may be higher, long-term living costs can be reduced compared to normal households. Additionally, improved health outcomes and environmental preservation can result from these sustainable practices in housing units.

2.3 Energy Performance

Energy performance in housing units is a critical factor in ensuring environmental sustainability, affordability, and enhanced living comfort. Starting with the environmental impact, energy performance strategies can significantly reduce greenhouse gas emissions. Energy-efficient homes contribute substantially to lowering the overall carbon footprint. According to the International Energy Agency (IEA), buildings account for about 28% of global energy-related CO_2 emissions. Additionally, the reduced need for fossil fuels due to lower energy consumption results from implementing energy performance strategies.

Economical benefits can also be derived from applying energy performance strategies to a project. As mentioned before, these strategies generate long-term savings due to lower energy consumption. Furthermore, energy-efficient housing features are attractive to buyers, increasing property value. Overall, the key aspects to consider for energy performance are: energy consumption, energy efficiency, thermal comfort, and air quality.

2.5 Adaptive architecture

Adaptive architecture is an approach to design that focuses on flexibility, resilience, and sustainability. It addresses the needs of users, ensuring that buildings can adapt to changing conditions over time. Among the main principles of adaptive architecture are flexibility in spaces, meaning that these spaces can change depending on the necessities of the user. Resilience is also a key factor in adaptive architecture, as it is designed to adapt to and withstand adverse conditions such as climate change. This involves enhancing structures and paying close attention to the materials used.

Sustainability is another key factor in adaptive architecture. Sustainable designs minimize environmental impact through the smart selection of materials and the use of renewable resources. Finally, adaptive architecture is a user-centric approach, focusing on the needs of the user to create spaces that suit their specific requirements.

Moving on to the benefits of this type of architecture, it is important to highlight economic efficiency. Adaptive architecture can lead to significant cost savings over the life of a building. Flexible designs reduce the need for costly renovations, while energy-efficient systems lower utility bills. Additionally, resilient buildings often have lower maintenance and repair costs (U.S. Department of Energy, 2022). Environmental benefits also stem from adaptive architecture, as this type of design reduces the environmental footprint. Energy-efficient systems and renewable resources decrease greenhouse gas emissions, while green spaces and urban density help preserve natural habitats (USGBC, 2021).

Out of the real-world applications of adaptive architecture, two stand out in reference to this project. First is the climate-responsive design, which needs to address climate conditions through the use of passive design strategies. Secondly, the user-based design is crucial, considering one of the main concerns of this project is the population in Bowen Island.

3 Affordable housing concept case studies

4.1 Cottages at Greenwood Avenue (Seattle, Washington)

Image 1: Aerial view of Cottages project - (Chapin, n.d., "Greenwood Avenue Cottages")

The Cottages project at Greenwood Avenue, located in Seattle, Washington, was developed to face the increasing need of affordable homes in a city known for the high real estate costs, mainly for older adults and low- and medium-income families. Seattle is facing an affordability crisis that is leaving many residents out of the traditional housing market. In this context, Cottages project at Greenwood Avenue is offering a small housing model that maximizes the shared space, reduces living costs and generates a viable alternative for those looking for affordability without sacrificing life quality. This emphasis is aligned to our objectives in the Bowen Island project, centered on developing affordable multifamily houses for post-parental adults, in a specific lot, in order to reduce living costs and optimize the terrain uses (Chapin, n.d.).

The Cottages project consists of 5 small houses in 1 lot, with a capacity to accommodate between 8 and 12 people. Each house has a surface of around 60 and 8 square meters, they are designed to bring comfort and functionality in a reduced space, with floor plans strategically distributed to remove unnecessary areas. This allows residents to have a manageable home at an affordable cost, especially for old adults that doesn't require a big house anymore. In the Bowen Island project, the disposition is similar, where the main idea is to construct approximately 10 houses in a determined lot, to significantly reduce the acquisition and maintenance costs for the residents. In this way, the downsizing of the houses and the efficient use of the space contributes to make these houses affordable to the habitants that are looking for an easier and more economic life (The Cottage Company, n.d.).

In terms of cost, Cottages at Greenwood Avenue has had a notable economic impact, both for its residents and for the general neighborhood. Before its development, the average price of a house in Seattle was around $800,000 USD, which left out of the market a lot of older adults and young families. With this project, each unit was offered between $350,000 and $450,000 USD. practically half of the average price in the city. This, not only helped the accessibility to the property, but also demonstrated the viability to create an economic model of compact and affordable dwelling. This works as a reference for our project in Bowen Island, due to the similar model of densification, in which one lot could make affordable houses in a region where the terrain and construction costs are high and rising, allowing post-parental adults to remain in their community without the economic charge of a traditional dwelling (The Cottage Company, n.d.).

In relation to sustainability, Greenwood Avenue also is highlighted for the use of sustainable materials and energy efficient technologies. The houses were constructed to minimize the environmental impact and reduce the long-term costs through the incorporation of low consumption technologies and efficient insulation, which has allowed to reduce the energetic cost by 30% in comparison with an average house. This is relevant for Bowen Island proposal, due to the sustainability importance of it, in which by applying energy efficient systems and ecological materials on the construction the houses can low the services costs, making the project not only affordable at the purchase stage, but also in its useful life. This aspect is crucial for the residents of low and medium incomes, who benefit financially from a house with less energy consumption, supporting the environmental objectives of the municipality (The Cottage Company, n.d.).

Finally, the design of The Cottages project foments the community life through the disposition of the houses around a green community space. This space promotes the interaction and belonging sense between the residents, generating a supportive and social cohesion environment. The objective of creating an active and connected community through shared spaces as gardens and reunion areas is also an essential element for the success of the present project of this thesis. In older adults case, this design could offer a support network with neighbors that helps to strengthen social bonds and fight against loneliness. The model of Greenwood Avenue demonstrates that this integration of community spaces can improve life quality of the residents and foment a great coexistence (The Cottage Company, n.d.).

In conclusion, the development of The Cottages at Greenwood Avenue works as a direct and applicable referent for the Bowen Island proposal, by demonstrating that a multifamily community can be affordable, sustainable and cohesive. The compact housing design, the sustainability principles and the emphasis on the community are aspects that ensure a positive impact on the residents, providing to post-parental adults an affordable, respectful environment and socially cohesive house (Chapin, n.d.).

Image 2: Shared spaces
(Chapin, n.d., "Greenwood Avenue Cottages")

Image 3: Energy efficient strategies applied
(Chapin, n.d., "Greenwood Avenue Cottages")

3.2 Montgomery County, Maryland

Image 1: Affordable houses project in Montgomery County - (Montgomery, n.d., “Affordable Housing”)

The low income housing scheme in Montgomery County Maryland is a solution to the growing problem of affordability and sustainability that affects the residents in the region regardless of their income class. This crisis is brought about by several causes, including the increase in costs of development, the finite amount of land, population evolution, and both the national and local policies. Given these challenges, the County has been implementing the Moderately Priced Dwelling Units (MPDU), which has promoted inclusion by making it possible for low and moderate-income people to access decent housing in high-cost regions by ensuring that 12.5 to 15 percent of the units in every new development are affordable. In a market where the median home value exceeds $500,000 USD, MPDU units, which range in price from $150,000 to $250,000 USD, offer an affordable option to families and seniors with incomes between 50% and 80% of the area median income (Montgomery County Government, 2024; Montgomery Planning, n.d.).

This model of inclusionary housing is applicable to Bowen Island, where the ultimate goal of creating a multi-family structure is to offer a form of accommodation for post-parent male and female adults who are situated in regions where there is high expense of living and availability of affordable housing is low. In addition, the Montgomery County project addresses the need to expand missing middle housing to meet the demand of those who need options between low-density neighborhoods and high-density districts. This policy allows for a gradual transition of single-family homes into higher-density residential areas, without eliminating existing single-family neighborhoods. To this end, transition areas have been identified where the zoning change will incentivize the construction of this type of housing, and recommendations have been made to facilitate the conversion of some properties into multi-family residences if the owners or developers decide to take advantage of these opportunities. This “missing middle housing” policy could be applied to Bowen Island to offer a variety of housing options on the same lot, allowing for multifamily development that maintains residential scale and integrates into the community, while addressing the need for affordable housing (Montgomery Planning, n.d.).

Similarly, in relation to sustainability, Montgomery County also uses energy efficient technologies and low environmental impact materials on the MPDU units. These implementation not only help to l lower the initial costs of construction, but also the operating costs, which reduced utility expenses by approximately 20% compared to a conventional house. For the Bowen Island project, the inclusion of sustainable elements is critical; incorporating energy-efficient systems, such as solar panels and efficient insulation, would not only reduce environmental impact, but would allow residents, especially seniors, to maintain an affordable standard of living in the long term. This sustainable design contributes to the affordability of the housing and facilitates a maneagable environment for the residents (Montgomery Planning, n.d.).

Another important aspect of the Montgomery County project is the preservation of long-term affordable rental housing for moderate- and low-income families. By following the policies and practices that help maintain and expand this affordable rental options, the County objective is to ensure that residents have affordable rental options, a strategy that is also applicable on Bowen Island. As demand for affordable housing increases, having an affordable and sustainable rental infrastructure ensures that older adults on Bowen Island can remain in their community without being displaced by rising living costs (Montgomery County Government, 2024).

Last, Montgomery County too mentions that if affordable units are built thereis a greater community feeling and even less economic disparity. Since mix of MPDU's in standardized neighbourhoods promotes interaction of people from different socio-economic classes, it creates an encouraging atmosphere of support and social integration. This approach can be modified for Bowen Island, where the shared areas of multifamily project would assist in socializing and forming residents' support networks. For post-parent adults, these common areas are quite useful in that they provide an environment where interactions and collaborations can occur. Therefore, these factors address the issue of isolation (Montgomery Planning, n.d.).

In conclusion, the development of The Cottages at Greenwood Avenue works as a direct and applicable referent for the Bowen Island proposal, by demonstrating that a multifamily community can be affordable, sustainable and cohesive. The compact housing design, the sustainability principles and the emphasis on the community are aspects that ensure a positive impact on the residents, providing to post-parental adults an affordable, respectful environment and socially cohesive house.

Image 2: Housing typology
(Montgomery, n.d., "Affordable Housing")

Image 3: Proposal scenario
(Montgomery, n.d., "Affordable Housing")

4 Energy-efficient housing concept case studies

4.1 BedZED (Beddington Zero Energy Development)

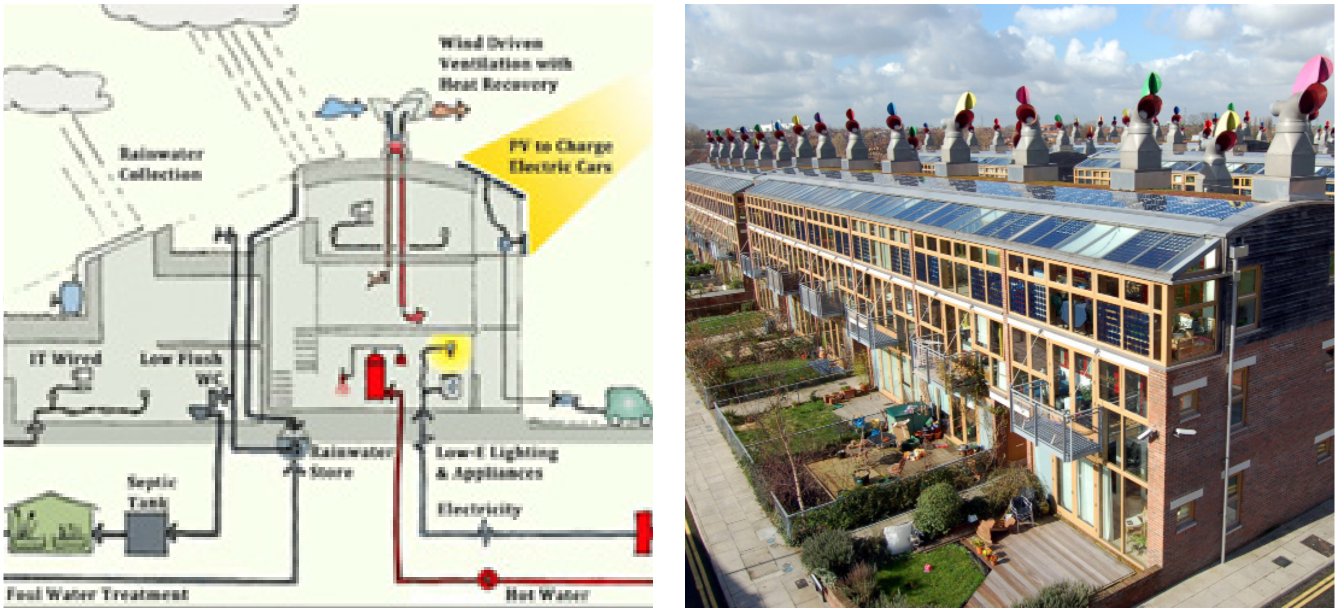


Image 1: Aerial view of Cottages project - (Chapin, n.d., "Greenwood Avenue Cottages")

BedZED (Beddington Zero Energy Development) is an innovative mixed-use sustainable community located in London, UK. This project is the UK's first large-scale, carbon-neutral community designed to promote energy efficiency and sustainability. For this project analysis it is important to take into account the energy-efficient and sustainable characteristics, emphasizing its innovative design, technologies, and community-focused approach. These main characteristics can be taken as a reference for a housing proposal in Bowen Island.

In terms of design and energy efficiency this project applies two main strategies. First, BedZED employs a passive solar design, which is essential to its energy efficiency. The buildings are oriented to maximize sunlight exposure, reducing the need for artificial lighting and heating. Also, high levels of insulation, including triple-glazed windows and thick walls, minimize heat loss, ensuring that homes remain warm in winter and cool in summer. On the other hand, BedZED also uses green roofs which reduce the heat loss and helps to mitigate the heat island effect. As well as ventilation systems which capture heat from outgoing air to warm incoming fresh air, further enhancing energy efficiency.

In terms of results and impact, BedZed has had remarkable success in reducing energy consumption and carbon emissions. These homes use 81% less energy for heating, 45% less electricity and 58% less water than the UK average home. The project's low carbon design and the different renewable energy systems that are applied in the project have had a significant effect on the carbon footprint. This project serves as a reference for the housing project that is going to be proposed in Bowen Island as it serves as an energy efficient and sustainable multifamily model that addresses the environmental challenges and enhances the quality of life of its residents.

4.1 VB56 House(Netherlands)

This project is promoted as entirely energy-neutral, featuring energy-efficient systems and materials. It is built from 80% wood, including the structure, cladding, stairs, and frames, which significantly reduces the carbon footprint of the project. By using accessible materials and incorporating prefabricated pieces, the carbon footprint from transportation and construction is lowered.

In terms of design, the house is composed of two stories. The first floor includes all of the social areas with an open space concept and two of the bedrooms. The second floor features a third bedroom.

The VB56 House by VANBOOM is a prime example of adaptive architecture that prioritizes sustainability, energy efficiency, and user-centric design. This project sets a new standard for future homes, demonstrating that it is possible to create beautiful, functional, and environmentally friendly living spaces.

This project is relatable to Bowen Island's proposal, as one of the main materials produced in British Columbia is wood. Using this material will significantly reduce the carbon footprint of the project. Additionally, the project must prioritize energy performance, similar to this one. In this case, the project pays close attention to energy consumption by heating. The house insulation provides enough airtightness that it is not necessary to use large amounts of energy to heat the space.

5 Palafitic architecture case studies

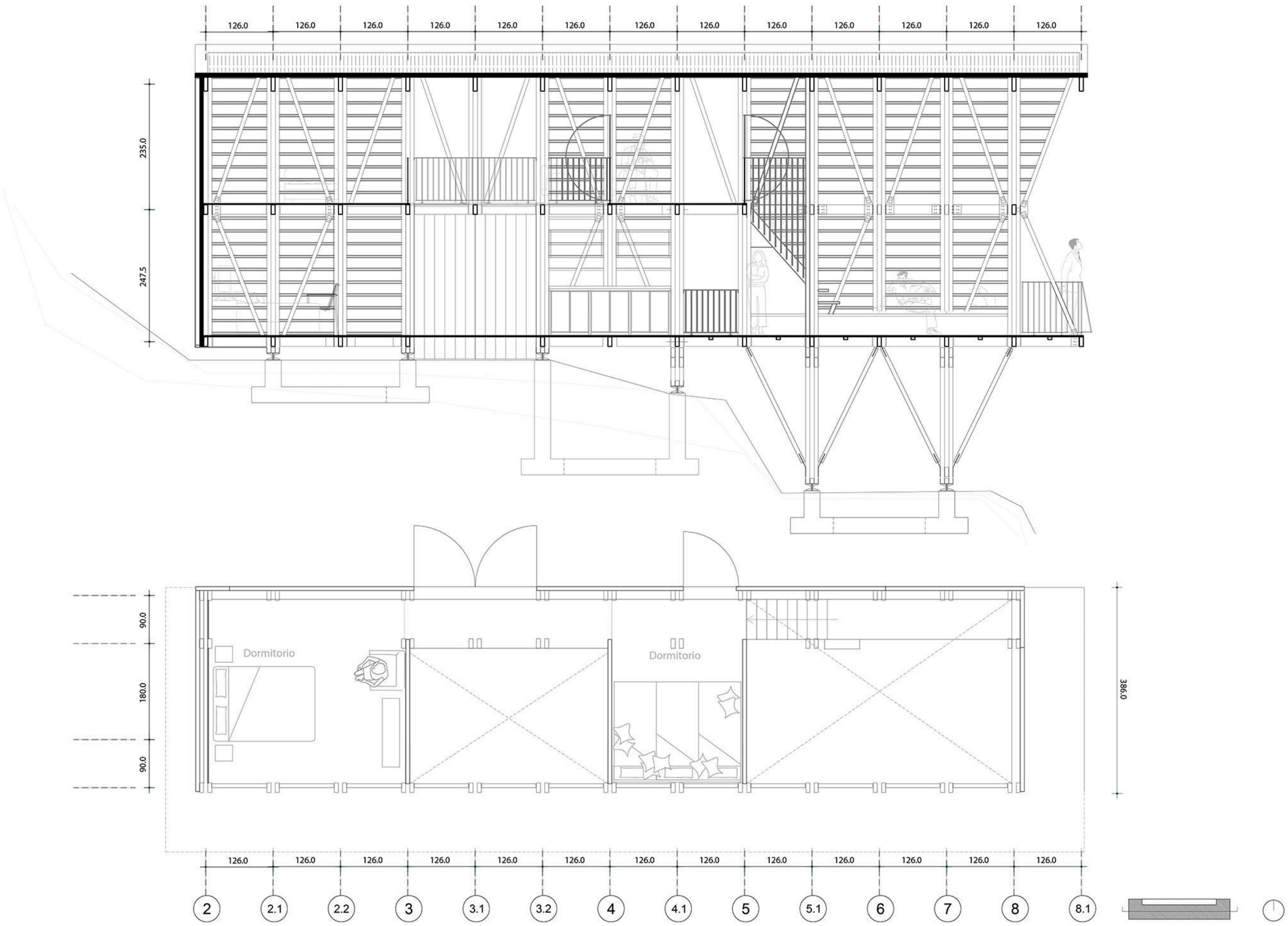
5.1 La Casa Tejida - Santiago Pradilla and Zuloark

Image 1 and 2: Picture taken by Federico Cairoli, 2021

The translation of Casa Tejida is “Woven House.” This concept is derived not only from its woven wall technique but also from the community interaction fostered by its construction, which somehow wove the community together. This project is located in an isolated area of Colombia and seeks to highlight the responsibility towards the environment from the architect’s standpoint and the community-building style. It also emphasizes social construction, open and intelligent design, biodiverse architecture, and low environmental impact, aiming to innovate rural development in Colombia. (García, 2021).

Among the main characteristics of the house is the use of Pacific housing concepts, which are derived from many rural areas in Colombia, such as the coffee regions with steep slopes in the terrain. This strategy is based on pre-Hispanic architecture, where they used alternating buried columns to support the house easily in case of maintenance of the structure.

This strategy of palafitic structure can be applied in Bowen Island project in the sense of elevating the house over the territory without harming it by excavating. This also prevents any type of infiltration since the lower level will be separated from the ground and insulated. Additionally, this creates an advantage in terms of airtightness and comfort inside the house.



Extracted from Metalocus, 2024

6 Chapter conclusions

After analyzing and understanding different case studies with values common to the proposed project, it is important to underline some applicable strategies. First, recognizing sustainability as a common factor in the project and acknowledging all associated factors, such as affordability derived from the proper use of energy efficiency strategies, and energy consumption data resulting from sustainable practices. Additionally, identifying the areas that need consideration based on an affordable project in Bowen Island.

From this chapter, it can be concluded that considering sustainability as a path for affordable housing units is possible. Moving forward, it is important to consider the context in which these values can be applied and how they will affect the specific population targeted in the project.

02

Project context

1 Historical context

1.1 Historical timeline

Bowen Island has presented significant transformations, in terms of physical changes, improvement of transportation to Vancouver and major demographic shifts. These trends have established the foundation for challenging dialogue around affordable, energy-efficient multifamily construction options, particularly accommodating post-parental age adults who are contributing to continued problems associated with an aging demographic and rising housing pressure in general.

In the 1800's, Bowen Island's primary population was the Squamish indigenous people, living there for hunting and fishing. European settlement in the mid-19th century introduced new activities, such as logging, becoming the main economic activity since the 1870s, where they first arrived. .By the late 19th century, Bowen Island had become a source of recreation for Vancouver residents who vacationed on the island in small cabins and participated in diverse tourism activities. Even with logging the island was still mostly untouched on a physical level. There was little infrastructure development, so much of the island's natural environment persisted (Bowen Island Properties, 2024).

Bowen Island had blossomed into a recreational destination by the 1920s, with ferries from Vancouver running on a regular basis. The Union Steamship Company ran regular ferry services allowing day trips and extended stay vacations. Tourism was notably encouraged through the construction of hotels, rest and amusement parks. Nevertheless, the island remained largely rural. From the physical standpoint, docks, resorts and recreational facilities developed, while the natural habitat remained untouched. New ferry services, between the island and the mainland, established a more enduring connection with Vancouver (Bowen Island Properties, 2024; Bowen Island Museum & Archives, n.d.).

In the 1950s there was an increase in permanent residents, as highways and mobility improved, the Island achieved a quieter lifestyle away from the urban activity but close to Vancouver. Zoning standards began to be enforced in the 1970s to help control expansion while preserving a balance of development and nature preservation on the island. The majority of residential development at this time was single-family housing with limited multifamily options. With the arrival of more houses on the island, alterations to its physical landscape became more noticeable, but considering the environmental impact, by preserving its ecological features and minimizing the harm. The ferry remained an important transportation link for the island's resident workforce to Vancouver, but as its population grew, so too did pressure on its infrastructure. The demographic situation presented a moderate increase in population on Bowen Island as families and retirees were attracted to the natural beauty of the locale and yet still close enough to consider commuting back into the city (Bowen Island Properties, 2024; Bowen Island Museum & Archives, n.d.).

During the 1980s and 1990s, conservation measures became a much bigger issue with large proportions of the island being set aside as conservation areas and natural parks, limiting further urban development. In 1999, Bowen Island became a municipality after decades of being governed directly by the province, allowing residents to have more control on the land uses and planning development. Development stayed centered on single-family homes, and multifamily housing practically did not exist. But while the physical landscape evolved with new homes going up, pieces of land were left undeveloped because of conservation statutes. Bowen Island was not as distinguished as it is now, the transportation was only by boat via the ferry system run by BC Ferries, which greatly contributed to keeping Bowen Island so rural.

The population growth was slow demographically, the retirees and families with children still dominate the setting, but high property values began to make it a difficult place for the young residents and middle-income families who used to find their way to Silver Lake (Bowen Island Museum & Archives, n.d.).

During the early 2010s Bowen Island was in the struggle of the housing affordability crisis. This inflated property values, placing home ownership out of reach for younger families as well as for many local middle-income residents and post parental adults hoping to downsize. The most recent Housing Needs Assessment in 2018 indicated an urgent demand for different kinds of housing types, including affordable rental units and apartments, especially for low budget seniors. Despite this, the island was still largely reserved for exclusive large single-family homes, limiting the affordable housing choices. The built pattern of the island did remain low density residential, and preferences for higher-density energy-efficient housing began to emerge. Also, the ferry connection was still a problem, where getting to Vancouver was limited due to the reduced schedules, but discussions on transportation improvement started. The older population was growing demographically and the uncertain housing situation continued to be a challenge, with an increasing number of retirees and middle-class families in distress on the island (Bowen Island Properties, 2024).

Nowadays, Bowen Island is facing a demanding moment in its density, where a large part of the island has been conserved and consequently it remains largely low-density. But the inability of people and their basic human needs to scale or be reduced has now led to increasing problems of housing need and cost in the system. Zoning restrictions designed to preserve the island's nature have also made it difficult to add any new projects, particularly multi-family housing. On the other hand, new developments to cover the housing demand, should be energy-efficient proposals, that not only ensures affordability but also long-term costs and life quality (Bowen Island Properties, 2024; Bowen Island Museum & Archives, n.d.).

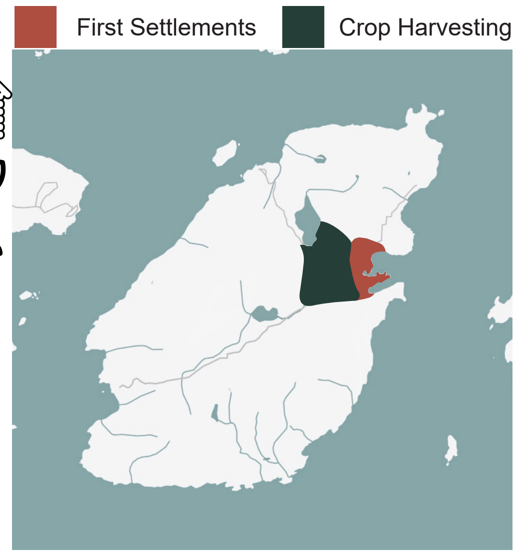
The main route to Vancouver is still via the ferry and transportation remains an ongoing challenge. During 2024, additional ferry services or new options such as water taxis are proposed to be chartered in light of the expected increase on a long-term solution regarding the increasing local population. Better transport (both for tourists and residents who commute to the mainland) would do a lot to help new developments, but the island has a lack in infrastructure roads, water and sewage system to support a large inflow of residents, so any new housing will have to include substantial upgrades in these areas. Bowen Island is still aging, with a big population of post parental adults and seniors who are looking for smaller and affordable homes, which remain on the community urban planning negotiations (Bowen Island Properties, 2024; Bowen Island Museum & Archives, n.d.).

In conclusion, these changes in Bowen Island's timeline represent an evolution from rural, getaway-based community to suburban enclave confronted with the housing pressures of today. Due to its few connections with Vancouver, dependence on single-family homes, and increasing demand for alternatives that are actually affordable, the community is needing energy-efficient multi-family housing concepts better suited for post-parental adults. Any changes moving forward must represent a balance with the island's natural environment, while also achieving more sustainable and affordable housing solutions that will serve an aging population without losing sight of the natural and community values that sets Bowen Island apart.

First Establishments
Early records show the Squamish Nation hunted, fished, and used the island as a neutral meeting place, calling it “Fast Drumming Ground.”
(Bowen Island Properties LP, n.d.)

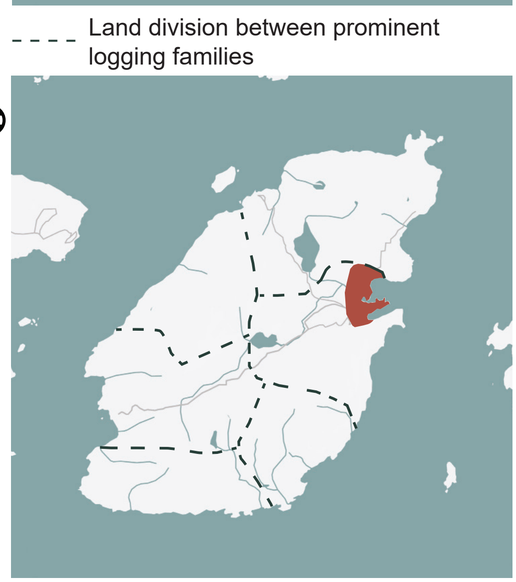
1860
Captain George Henry Richards named the island “Bowen Island” after Rear Admiral James Bowen
(Bowen Island Properties LP, n.d.)

1870
First loggers arrived, closely followed by early settlers.

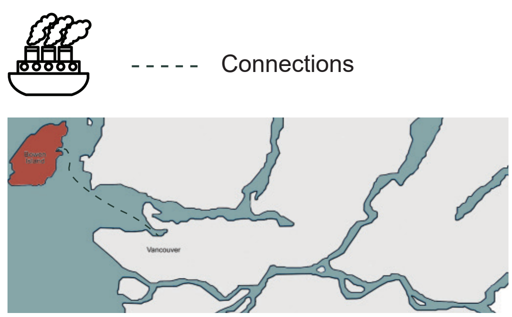


1874
The first land preemption was made by white settler William Eaton, who claimed 160 acres south of Killarney Lake. To encourage settlement, Britain introduced a system allowing settlers to claim Crown lands if they cleared, fenced, built homes, and cultivated crops.
(Bowen Island Properties LP, n.d.)

1880
Prominent pioneer families from Vancouver acquired large land holdings. The local economy was driven by logging, fishing, farming, brick production from a rare blue clay deposit, and a dynamite plant, later transitioning to tourism as a major industry.
(Bowen Island Properties LP, n.d.)



1890
Bowen Island became a popular vacation spot for Vancouver residents, who stayed in small cabins and enjoyed various tourist activities. Despite logging, the island remained largely undeveloped, with minimal infrastructure, preserving much of its natural environment.
(Bowen Island Properties LP, n.d.)



1900
The earliest subdivisions occurred at Millers Landing (35 lots), the north shore of Deep Bay (61 lots), Scarborough (150 lots), and northwest of Killarney Lake (32 lots).

1920's
By the 1920s, Bowen Island had become a popular recreational destination, with regular ferry services from Vancouver. The Union Steamship Company operated ferries, enabling both day trips and extended vacations.
(Bowen Island Properties LP, n.d.)

1940's
During the 1940s, the artists' colony known as Lieben served as a retreat for many renowned Canadian authors.

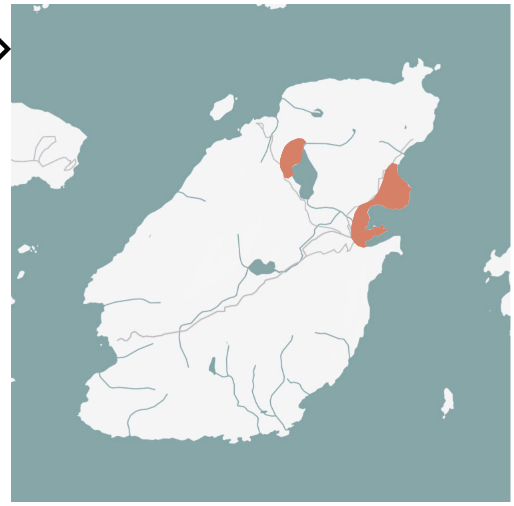
1957
The first car ferry to Bowen was later replaced by BC Ferries, allowing people to live on Bowen Island and commute to Vancouver.
(Bowen Island Properties LP, n.d.)

1960
Union Steamship resort closed in the 1960s the island returned to a quiet period of slow growth.
(Bowen Island Properties LP, n.d.)

1970's - 1990's
Families moved to Bowen because real estate prices were more affordable than in Greater Vancouver, and the commute was comparable to a commute from suburbs.
(Bowen Island Properties LP, n.d.)

1999
Bowen became the first (and only) municipality within the Islands Trust.

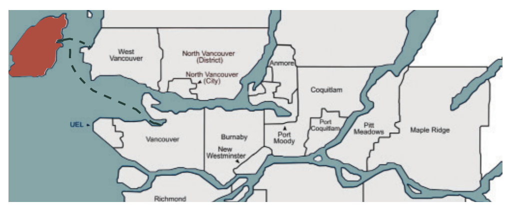
2010's
This inflated property values, placing home ownership out of reach for younger families as well as for many local middle-income residents and postparental adults hoping to downsize.

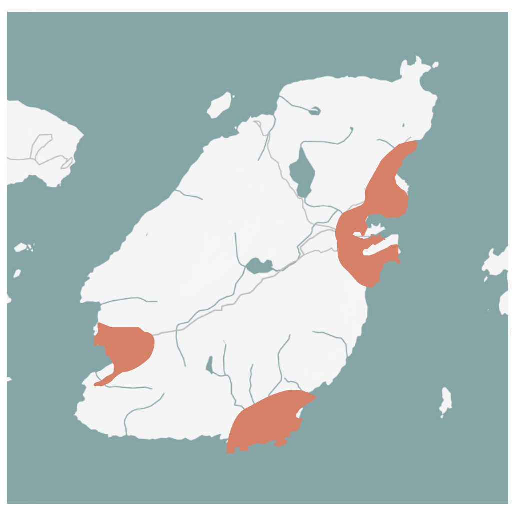


Captain Jack Cates' Resort at Deep Bay

Ferry transportation improved the conection with Horeshoe bay

- - - - - - Connection





Highest popultion density areas

2 Demographic situation

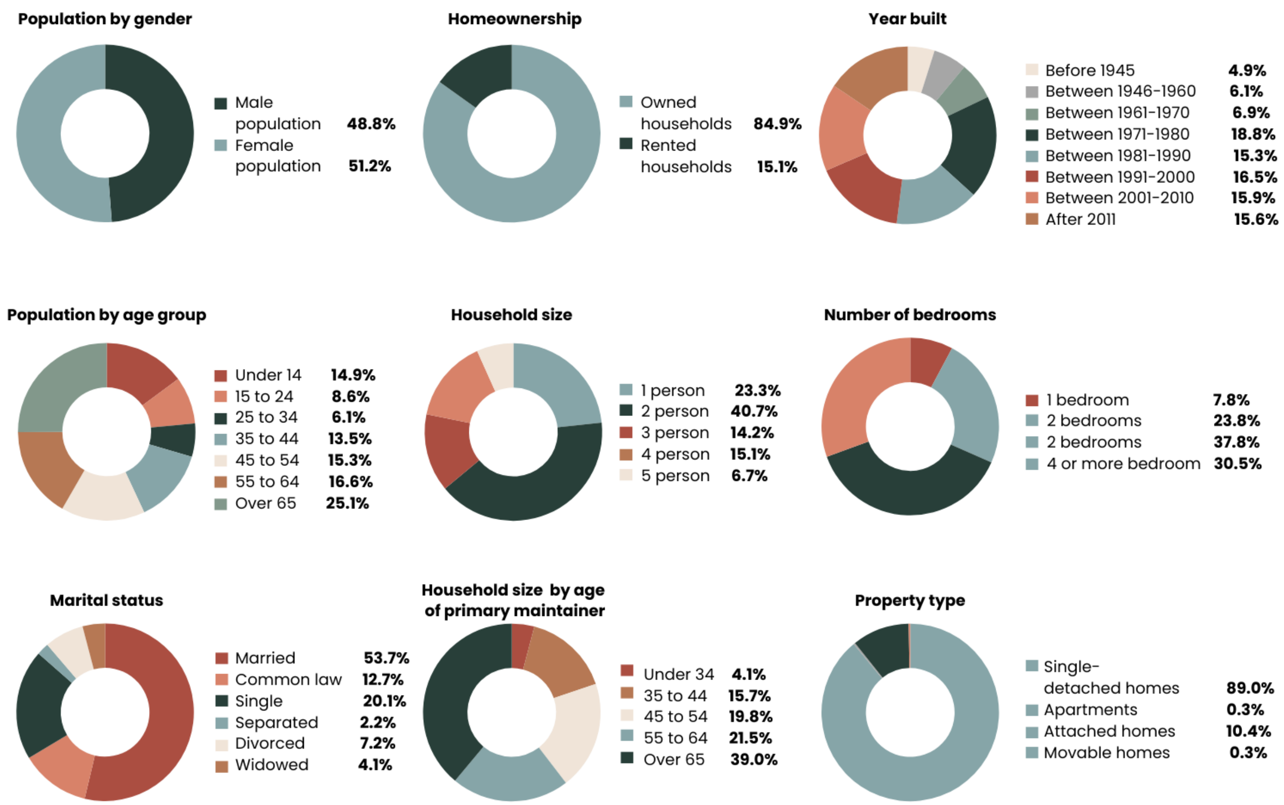
2.1 Demographic Timeline

Bowen Island has a rich history dating back to the earliest records of the Squamish Nation, who hunted, fished, and used the island as a neutral meeting ground. The Squamish name for the island is Xwlíl'xhwm, meaning "Fast Drumming Ground." Early settlers observed shake dwellings and a smokehouse in Snug Cove. The first loggers arrived in the 1870s, followed by early settlers. In 1874, William Eaton became the first white settler to preempt land on the island, claiming 160 acres south of Killarney Lake (Bowen Island Historians, 2021).

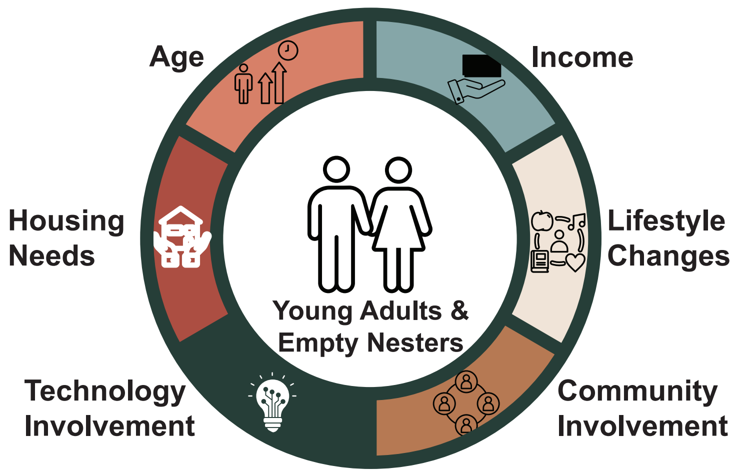
By the late 19th and early 20th centuries, Bowen Island saw significant development with the establishment of resorts, logging, fishing, and farming. The Union Steamship Company played a major role in developing the island into a popular resort destination, known as "The Happy Isle" during the 1920s to 1940s. The island's population continued to grow, reaching approximately 5,000 by 1991 (Bowen Island Municipality, 2021).

In recent years, Bowen Island has maintained steady population growth, with the 2021 census recording a population of 5,000. The island's appeal as a scenic and tranquil place to live continues to attract residents, contributing to its ongoing development and preservation of its natural environment (Statistics Canada,nd).

2.2 Current situation



Population Target



Empty Nester

Age: Typically in their 50s or 60s, empty nesters are navigating the transition from active parenthood to a more independent lifestyle.

Income: Empty nesters typically have an average income ranging from $60,000 to $100,000 per year. This can vary based on factors such as career, location, and savings.

Technology Involvement: Empty nesters are increasingly getting into technology, using digital tools to stay connected with family, manage finances, and explore hobbies.

Housing Needs: Empty nesters often consider downsizing to a smaller, more manageable home. They may look for single-story homes or properties with fewer maintenance requirements.

Lifestyle Changes: With the kids gone, they pursue hobbies, travel more, and engage in social activities, with a focus on personal health and wellness.

Community Involvement: Many increase their community engagement by taking on volunteer work or even part-time employment.

Young Adults & Workers

Age: Young adults, ranging from 15 to 34 years old, represent 20% of the population. On the other hand, workers can vary in age, and this target group is based on income and the availability of small housing units on the island.

Income: Income in this case can vary since it includes both workers and students who wish to remain on the island.

Technology Involvement: In general terms, the younger population is particularly tech-savvy, with a notable presence of remote workers and digital nomads.

Housing Needs: Housing needs in this group are based on the work or activity they do. Many young adults are remote workers, making it necessary to have a workspace at home.

Lifestyle Changes: In terms of changes, this population includes people who are moving out of their parents' houses and don't want to leave the island, as well as workers from the island who find it more affordable to live there.

Community Involvement: Community involvement in this specific group is based on the recreational and social activities available on the island.

2.3 Prediction

Elderly Population

Based on the data from the 2021 Census, Bowen Island has a population of around 3,700 permanent residents, with 25% aged 65 and over. This population is expected to grow as trends show that since 2011, it has increased by 6%. This suggests that the demand for elder population housing is going to increase. This is based on the idea that older adults prefer not to downsize outside of the island.

According to national and regional projections, it expected a consistent and gradual rise in the 65 and over population on the island is expected, impacting the housing demand in different ways. There are 3 main trends that will impact on the future housing projections. The first one is that by 2030, as the baby boomer generation continues to age, around 35% of the island population will be over 65. The second one is the mi¬gration trend, where retirees and semi retirees from Great Vancouver are loo¬king for a more natural and peaceful environment close to the city. The last one is the housing preferences, where many of the post parental adults residents are looking for smaller and community living houses rather than the single family homes where they actually live. This raises the need for affordable and energy efficient houses, that ensures a lower living cost and takes care of environmental concerns.

This represents the actual multifamily housing demand, that by 2030 will grow as the post parental adult population increases, representing an urgen¬cy of multifamily units' development.

Young Population

Currently there's a need to enhance the supply of rental housing to accommodate single person households, especially those who may not be able to afford ownership. Although this portion of the population doesn't have a significant impact on the housing demand, the creation of supply can result in a diversification in the population pf the island by not having a significant majority of aging persons.

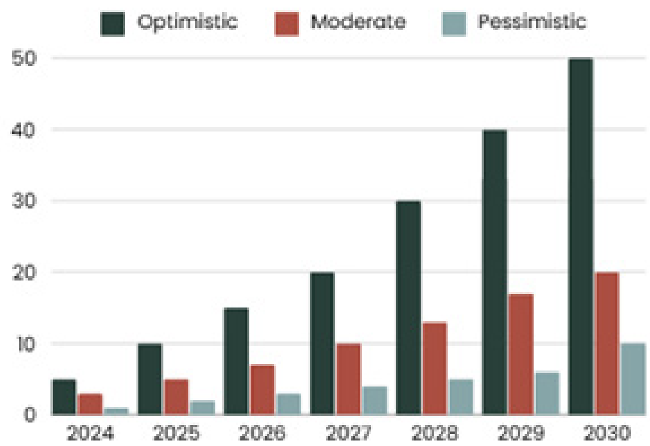
Housing Demand Forecast:

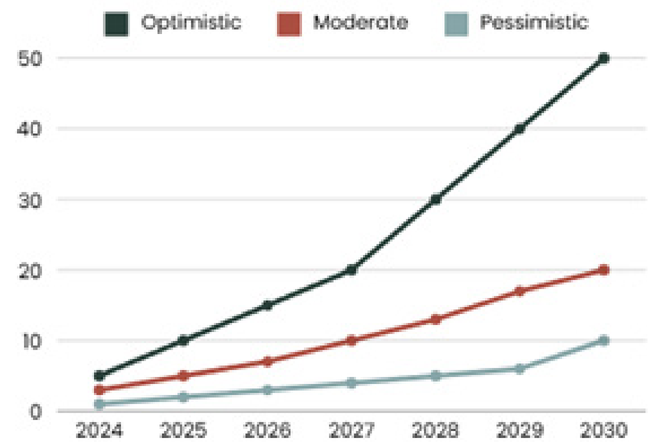
By 2030, the demand for multifamily, energy-efficient housing on Bowen Island is projected to grow as the population of post-parental adults increases. This may require an additional 20-30 multifamily units, depending on exact migration trends and available land for development. On the other hand, diversifying the housing supply by adding single-person households can significantly impact housing demand. As interest in the island rises, catering to single-person households can represent a significant opportunity for the housing market. This approach can provide a balanced and sustainable growth strategy for Bowen Island, ensuring that the diverse needs of its residents are met.

Physical Context Analysis:

Land Use and Zoning:

Bowen Island's land-use regulations are designed to maintain its rural and natural character, which limits lar¬ge-scale developments. However, mul¬tifamily housing proposals that focus on affordability and sustainability have a higher chance of receiving approval, especially if they align with Bowen Is¬land's Official Community Plan (OCP) and sustainable development goals.





Graph done by ourselves with information taken from: https://islandstrust.bc.ca/document/housing-needs-report-bowen-island/

Conclusion

The most likely scenario for Bowen Island's demographics and physical context over the next decade is moderate growth in demand for multifamily, energy-efficient housing for post-parental adults and young population. This will require careful environmental planning, policy support, and investment in sustainable infrastructure to accommodate this demand while preserving the island's natural character. Also, it would require a diversification in the household supply on the island.

3 Analysis of housing needs

3.1 Composition and trends in household size

On Bowen Island, the average household size has decreased considerably in the recent years, which is consistent with a provincial trend toward smaller housing units. The majority of households on the island are currently composed of one or two people, representing approximately two thirds of the population (Urbanics Consultants Ltd., 2020, pp. 15-16). This shift suggests a growing need toward more compact and flexible housing alternatives, mainly for those without children or older adults that prefer a housing option that doesn't require a lot of maintenance.

Household size	2001	2006	2011	2016
1 person	225 (20%)	300 (22%)	295 (22%)	340 (23%)
2 persons	440 (38%)	510 (38%)	505 (37%)	610 (41%)
3 persons	180 (16%)	220 (16%)	210 (15%)	210 (14%)
4 persons or more	300 (26%)	250 (23%)	295 (25%)	240 (22%)
Total Households	1,145	1,340	1,355	1,495
Total Population	2,957	3,350	3,385	3,670
Average household size	2.58	2.50	2.50	2.45

Table 1 (Household Size Composition on Bowen Island, 2001-2016)
Source: Urbanics Consultants Ltd. and Census 2001 - 2016

This table shows the trend of decreasing average household size and increasing one and two person households, reflecting changes in housing needs.

Private households by household type	BIM	GV	BC	BIM	GV	BC
One-census-family households	1,105	600,575	1,196,165	74%	63%	64%
Without children	550	226,325	527,795	37%	24%	28%
With children	550	374,250	668,365	37%	39%	36%
Multiple-census-family households	20	37,745	55,465	1%	4%	3%
Non-census-family households	375	322,575	630,340	25%	34%	33%
One-person households	340	275,485	541,925	23%	29%	29%
Two-or-more person households	35	47,090	88,415	2%	5%	5%
Total Private households	1,500	960,895	1,881,970	100%	100%	100%

Table 2 (Comparison of Household Types on Bowen Island, Greater Vancouver and BC, 2016)
Source: Statistics Canada – 2016 Census

This table compares Bowen Island to other regions, showing that the island has a significantly higher proportion of single-family households without children, an indicator of empty nesters. The evolution toward smaller houses is a key aspect to justify the multifamily housing need, designed for residents that require affordable and compact houses, ideal for older adults and young people that are looking to reduce costs and maintenance.

3.2 Income levels and affordability challenges

There is a significant disproportion in the income levels between the homeowners and renters on Bowen Island, which impacts directly the affordability. Generally, the 44% of households earn more than $100,000 annually, a high amount compared to the provincial average, but between the renters only the 39% meet this threshold, while 61% of them earn less than $60,000 (Urbanics Consultants Ltd., 2020, p. 23-24). This unequal income distribution creates a pressure on the rental market, where the high prices limit the majority of the people, particularly the ones with lower incomes, from access to affordable housing options.

Household income (2015)	BIM		GV		BC	
	#	%	#	%	#	%
Under $30,000	215	14%	182,755	21%	354,930	19%
$30,000 to $59,999	280	19%	216,020	24%	455,120	24%
$60,000 to $99,999	350	23%	229,545	26%	465,965	25%
$100,000 and over	660	44%	255,055	29%	607,850	32%
Total households	1,505	100%	883,375	100%	1,883,865	100%

Table 3 (Income Distribution, 2015)
Source: Statistics Canada – 2016 Census

This table is fundamental to illustrate how income affects households ability to afford different types of housing, especially for renters, who represent the majority of lower-income households.

Households	Median household income	Affordable purchase price	Single-detached $959,400	Rowhouse/ townhouse $730,000	Half duplex $735,000
Couple-only family	$ 98,560	$520,912	☒	☒	☒
Couple-with-children family	$ 124,672	$658,920	☒	☒	☒
Lone-parent Family	$ 58,752	$310,518	☒	☒	☒
Family income	$ 106,752	$564,209	☒	☒	☒
1-person households	$ 37,504	$198,217	☒	☒	☒
2-or-more person households	$ 106,880	$564,885	☒	☒	☒
Median household income	$ 89,856	$474,910	☒	☒	☒
Median renter household income	$ 56,791	$300,153	☒	☒	☒

Table 4 (Affordable Purchase Price for Middle-Income Families)
Source: Urbanics Consultants Ltd. and Statistics Canada – 2016 Census

This table helps visualize that many middle- and low-income households cannot afford single-family homes, reinforcing the need for multi-family models that offer an affordable option.

3.3 Affordability issues in the housing market

The housing market in Bowen Island is oriented mainly to single family independent houses, which have a considerable high purchase cost, with an average of $959,400, leaving these properties out of reach for the 84% of the households on the island (Urbanics Consultants Ltd., 2020, pp. 26-27). Additionally, the rent for a 3-bedroom home average is $2,200 per month, unaffordable amount for the 50% of the households.The impact of these prices affects significatively the population that depends on rent options or the ones with medium and lower incomes. The lack of affordable houses is a considerable barrier for young people and essential service workers, who are forced to destinate a substantial sum of their incomes to housing costs.

Shelter-cost-to-income ratios	BIM	GV	BC
Owner and tenant households with household income greater than zero	1,480	953,380	1,832,420
Spending less than 30% of income on shelter costs	1,065 (72%)	648,420 (60%)	1,320,210 (72%)
Spending 30% or more of income on shelter costs	415 (28%)	304,955 (25%)	512,210 (28%)
Owner in non-farm; non-reserve private dwellings	1,215	608,080	1,242,600
Owner households with a mortgage	710 (58%)	366,672 (60%)	733,134 (59%)
Households spending 30% or more of its income is on shelter costs	295 (24%)	154,452 (25%)	260,946 (21%)
Median monthly shelter costs for owned dwellings ($)	$ 1,304	$ 1,376	$ 1,149
Median value of dwellings ($)	$798,877	$800,220	$500,874
Tenant households in non-farm; non-reserve private dwellings	265	347,220	592,825
Tenant households in subsidized housing	25 (9%)	45,486 (13%)	77,067 (13%)
Tenant households spending 30% or more of its income on shelter costs	120 (45%)	151,041 (44%)	254,915 (43%)
Median monthly shelter costs for rented dwellings ($)	$ 1,246	$ 1,136	$ 1,036

Table 5 (Housing Cost to Income Ratio)
Source: Urbanics Consultants Ltd. and Statistics Canada – 2016 Census

This table shows the percentage of households spending more than 30% of their income on housing, indicating the level of financial stress in the market.

Dwelling types	Median sales price	Loan amount	Mortgage payment ($ monthly)	PITI ($ annual)	Qualifying household income ($ annual)	% of households that fail affordability test
Owner-occupied						
Single-detached	$ 959,400	$ 767,520	$ 4,518	$ 58,800	$ 195,999	84%
Rowhouses/townhouses	$ 730,000	$ 584,000	$ 3,438	$ 44,740	$ 149,134	76%
Half duplex	$ 735,000	$ 588,000	$ 3,462	$ 45,047	$ 150,156	84%
	Monthly rent					
Renter-occupied						
3-bedroom+	$ 2,200				$ 88,000	50%
2-bedroom	$ 1,750				$ 70,000	46%
1-bedroom	$ 1,250				$ 50,000	31%
Bachelor	$ 975				$ 39,000	20%

Table 6 (Proportion of Households Not Meeting Affordability Criteria)
Source: Urbanics Consultants Ltd. and Statistics Canada – 2016 Census

This table reinforces the argument that a large portion of the population has trouble accessing to affordable housing, emphasizing the importance of larger options offers for affordable multifamily houses.

3.4 Tenancy preferences and limited rental options

The tenancy preference in Bowen Island is inclined to ownership, with 82% of the households owning a property, a high percentage compared to other areas (Urbanics Consultants Ltd., 2020, pp. 29-30). However, this high property rate limits the rental market, which is fundamental for young workers and seniors who need low cost and maintenance houses. The lack of affordable rental options creates barriers for a lot of young people that want to settle on the island and for the older adults that can't or are not on their plans to assume the charge of maintaining a property.

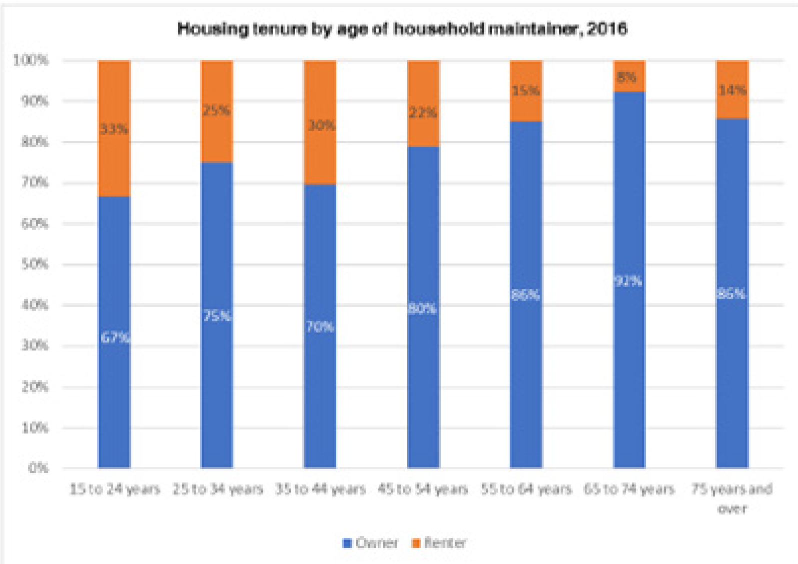


Figure 1: Housing tenure by age of household maintainer, 2016

Source: Urbanics Consultants and Statistics Canada–2016 Census

Tenure	2006			2011			2016		
	BIM	GV	BC	BIM	GV	BC	BIM	GV	BC
Owned	1,085	531,725	1,145,050	980	583,420	1,234,710	1,230	612,005	1,279,025
Rented	255	285,045	493,995	385	307,555	525,000	265	348,695	599,360
Band housing	0	455	4,920	0	330	4,925	0	190	3,590
Total occupied dwellings	1,340	817,225	1,643,965	1,365	891,305	1,764,635	1,495	960,890	1,881,975
Ownership rate	81%	65%	70%	72%	65%	70%	82%	64%	68%

Table 7 (Housing Tenure by Age of Householder, 2016)

Source: Urbanics Consultants and Statistics Canada – 2006, 2011, and 2016 Censuses

This table helps to understand how homeownership and renting are distributed by household age. Its relevant to show that many old and young people, key demographic groups, are in a rental situation, which reflects that they are the more affected due to the lack of affordable rental options.

Households	Median household income	Affordable monthly rent	Bachelor	1-bed	2-bed	3-bed+
			$975	$1,250	$1,750	$2,350
Couple-only family	$ 98,560	$ 2,464	✓	✓	✓	✓
Couple-with-children family	$ 124,672	$ 3,117	✓	✓	✓	✓
Lone-parent Family	$ 58,752	$ 1,469	✓	✓	☒	☒
Family income	$ 106,752	$ 2,669	✓	✓	✓	✓
1-person households	$ 37,504	$ 938	☒	☒	☒	☒
2-or-more person households	$ 106,880	$ 2,672	✓	✓	✓	✓
Median household income	$ 89,856	$ 2,246	✓	✓	✓	☒
Median renter household income	$ 56,791	$ 1,420	✓	✓	☒	☒

Table 8 (Affordable Rental Rates for Middle-Income Households

Source: Urbanics Consultants Ltd. and Statistics Canada – 2016 Census

This table highlights how the rent cost is out of reach for many low- and middle-income households, showing the necessity to offer affordable multifamily rental options.

3.5 Population growth and housing demand projections

For the upcoming years, projections suggest an increasing in the 25 to 34 and 65 and older age groups by 2031, with an expected increase of 81 and 99 houses for these age groups specifically (Urbanics Consultants Ltd., 2020, pp. 18-19). These projections highlight the need of planning houses that responds to the demand of young people that are looking for independence and older adults that require affordable and flexible housing options.

Population	2016	2021	2026	2031
Under 15 years	640	594	542	554
15 to 24 years	290	309	293	263
25 to 34 years	275	295	409	553
35 to 44 years	435	413	412	450
45 to 54 years	570	547	489	464
55 to 64 years	710	728	776	771
65 to 74 years	550	562	570	608
75 years and over	200	233	262	283
Total	3,670	3,681	3,753	3,946

Table 9 (Population projections by age group in Bowen Island)
Source: Urbanics Consultants Ltd., Statistics Canada – 2016 Census, and BC Stats.

This table is ideal to show the expected growth in different age groups and emphasize the increasing demand of adequate housing for young to senior population.

Households	2016	2021	2026	2031
15 to 24 years	15	15	13	13
25 to 34 years	80	86	119	161
35 to 44 years	215	204	204	222
45 to 54 years	300	288	257	244
55 to 64 years	400	410	437	434
65 to 74 years	325	332	337	359
75 years and over	155	181	203	219
Total	1,490	1,515	1,571	1,654
Housing needs				
5-year period		25	55	83
Annual		5	11	17
Annual average			11	

Table 10: Housing need projections by age group and tenancy types
Source: Urbanics Consultants Ltd., Statistics Canada – 2016 Census, and BC Stats.

This table shows the specific housing projections that will require affordable and accessible rental options, complementing the need of a multifamily housing offer.

3.6 Environmental preferences and sustainability in housing design

In Bowen Island, the preferences of the residents for sustainable houses are increasing, promoted by the desire of reducing the environmental impact and save on energy costs in long term. Multifamily houses, as they count with shared spaces and renewable energy systems, allows to reduce significantly the living costs for the residents and minimize the environmental impact. (Urbanics Consultants Ltd., 2020, pp. 34-35). The purpose of intergenerational energy efficient houses, will allow residents to reduce their carbon footprint, which is important in an island community with a sensitive natural environment.

Bowen Island	Average Rent	Median Rent	# surveyed
Studio	$975	$975	2
1-bedroom	$1,259	$1,250	8
2-bedroom	$1,930	$1,750	5
3-bedroom+	$2,370	$2,200	7

Table 11 (Average Rents in Occupied and Vacant Apartments)
Source: Urbanics Consultants Ltd.

This table helps to show how sustainable multifamily options in the rental market can offer a more affordable and environmentally solution
In addition, the Housing Needs Report of Bowen Island highlights the importance of fomenting sustainable houses through policies that incentive the densification and flexibility on the housing typologies.

4 Territorial analysis

4.1 Environmental analysis

Canada is a country with a big diversity of ecosystems, which represents their identity, key of the promoting efforts to its conservation. It has approximately 10% of the world's forests, diverse natural landscapes, protected areas, network of national parks, abundant freshwater resources (Including Great Lakes and numerous rivers). Nevertheless, it includes threads and challenges such as pollution, overuse, effects on water levels and climate change that has to be managed, in order to protect the sensitive areas and restore the degraded ecosystems.

Country's climate varies from temperate on the west coast to arctic conditions in the north, determining important decisions on housing projections due to the fluctuations along the year. Besides, the housing construction and operations projects in Canada have impacted the environment significantly on the carbon emissions and resource consumption, affecting the environment of the country. That's why, the main objective is to reduce these impacts through awareness construction, as energy efficient designs and sustainable building materials, in order to reduce the impact on the environment. Furthermore, Canada has committed to the Paris Agreement to reduce the greenhouse gas emissions through the transition of implementation of renewable energy. This helped to generate policies that follow the promotion of clean energy and reduction of carbon emissions (Bowen Island Conservancy, 2023).
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Bowen Island forms part of the country's natural richness, even though it is facing environmental challenges due to its reduced size and proximity to urban areas. Bowen island climate is temperate coastal, typical of the bio geoclimatic zone of the occidental coast, with humid and mild winter and warm and dry summer, in comparison to other regions of the country. Nevertheless, Canada is experimenting climate change effects, which includes an increase of the temperatures and extreme climate phenomena that affects the urban and protected areas of the country.

Also, the island climate requires specific design considerations for the energy efficiency, in which Bowen experiences both moderate temperatures and high levels of precipitation, which influences the durability and performance of the building. Insulation and effective humidity management is needed to ensure the efficient and sustainable design.

The island is a reservoir of significant biodiversity, with more than 2,200 registered species on the island and its coasts (iNaturalist, 2023). The absence of depredators led to the growth of deers, which affected the regeneration of the tree species, such as the Western Red Cedar (Bowen Island Conservancy, 2023). This generates an effect on the ecosystem, which alters the natural patterns of vegetation and species balance.

Besides, the island is home to several endangered species included in provincial protection (Bowen Island Conservancy, 2023), which means that the preservation and maintenance of these habitats is vital for this species and the general stability of the ecosystem. The majority of the island is classified as sensible ecosystems, which perform an important role in the provision of ecosystem services, such as filtered water, carbon storage and erosion protection, essential for biodiversity and human wellness (Bowen Island Conservancy, 2023).

An important aspect of the conservation in Bowen Island is the connectivity between the habitats, which indicates through an analysis made by "Metro Vancouver" that the island is a key point for specific species, reinforcing the essentiality of maintaining this ecologic corridor to allow the movement of species and ensure the resiliency against the climatic change (Metro Vancouver, 2021).

One of the biggest environmental challenges is the land use and its development. The housing needs have led to a huge residential increase, approximately 14% of the land uses of the island has been modified mainly by rural and recreational developments, even though the island is composed by 54% of sensible ecosystems as forests and wetlands (Bowen Island Conservancy, 2023), the population and tourism growth is risking the preservation of this areas. Between 2015 and 2019, the number of visitors passed from 6,000 to more than 30,000 per year (Bowen Island Municipality, 2020). This represents an important income source for the community, but also states challenges in terms of waste management, trail erosion, wildlife disturbance and air quality. For instance, Canada has implemented many wastes management and recycling programs in order to handle the situation.

In relation to the local policies of conservation of the island, there is an Official Community Plan (OPC), that promotes sustainable development and biodiversity protection. Through the collaboration of the "Island Trust" and the "Bowen Island Conservancy", there have been implemented policies to protect the greenways and to encourage the responsible use of land (Bowen Island Conservancy, 2023). These local initiatives are aligned with the Canada global commitments, such as the protection of the 30% of the land and water from the country for 2030, an objective from the COP15 agreement to stop the loss of biodiversity.

Furthermore, predictions point to rises in sea level, changes in precipitation patterns and higher temperatures, which will affect both terrestrial and marine ecosystems surrounding the island. The rise in the frequency of these extreme climatic events also risks the local infrastructure and can alter the sensible ecosystems (Bowen Island Conservancy, 2023).

In conclusion, the island is facing huge challenges in terms of housing development and natural resources conservation, which has to be managed carefully through the actual and future local policies, the regional initiatives and the community support. These actions have to be broad and rapid enough to meet the growing challenges of climate change and population and become a sustainable model. Moreover, maintain the approach of the sensible ecosystem protection, the ecologic corridor maintenance and the sustainable policies implementation to maintain the biodiversity on Bowen Island and ensure the role of ecological bastion of the Canada conservation efforts. Is crucial to consider the environmental activism movements, in which the educational programs and organizations work to promote the sustainable and efficient model of space (Bowen Island Conservancy, 2023).
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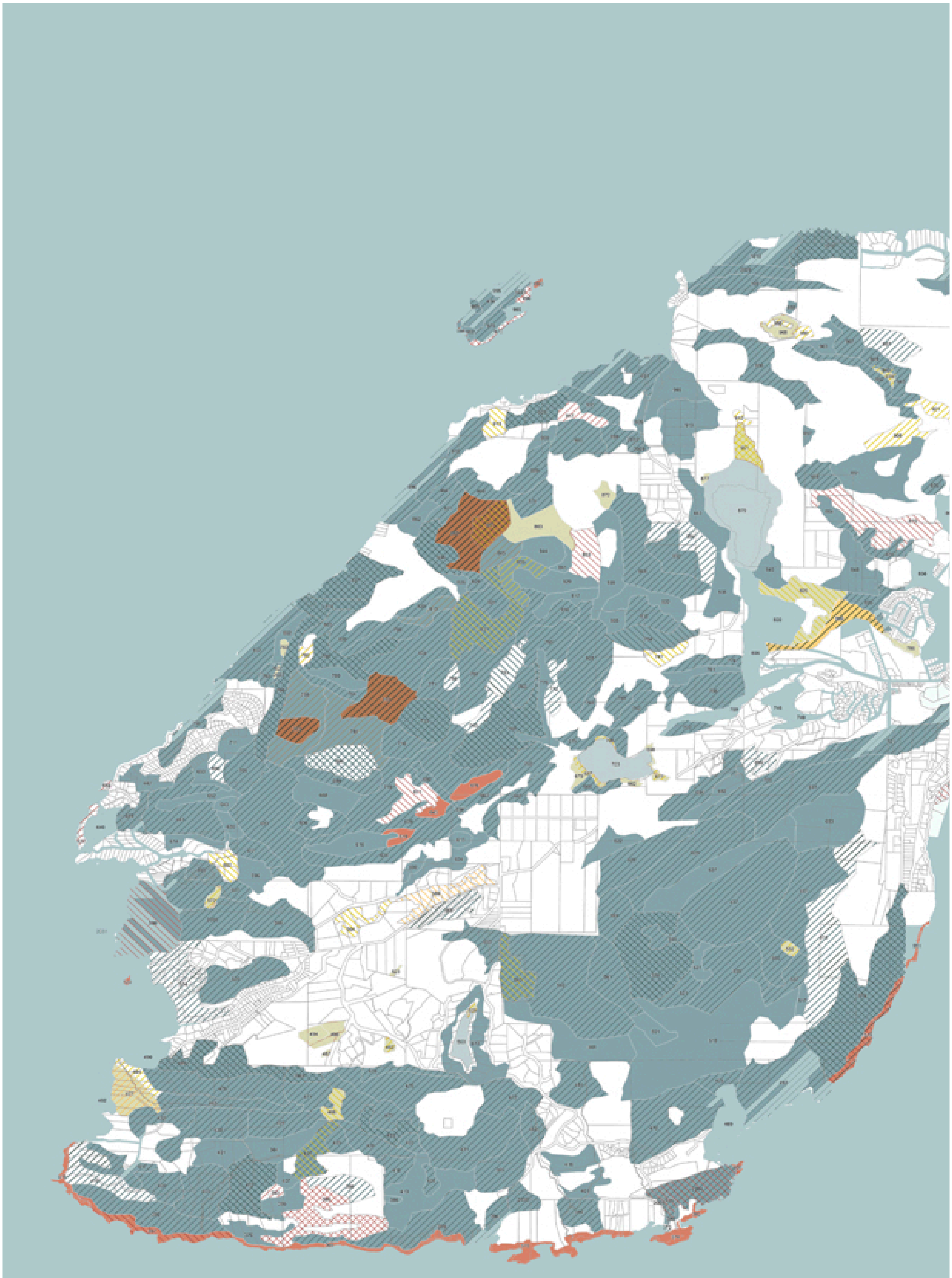


Map made by orselves with information taken from: https://bowmap.bowenislandmunicipality.ca/


VANCOUVER

4.2 Infrastructural analysis

Bowen Island manifests numerous cultural, socio-environmental and geographic factors regarding movement but mostly as an isolated community. With no mass transportation ridership available to the island due to its small scale, such constraints determine the extent to which residents can access essential services. The world is no longer such a big place with accompanying analysis which addresses to mobility issues on the Bowen Island with respect to its transport infrastructure, networks and integration (Bowen Island Municipality, 2020).

Transportation infrastructure

Ferry Services

Regular ferry service remains the only way to leave and enter Bowen Island in the region, giving access to Horseshoe Bay in the mainland. Both commuting residents who work in the mainland and require healthcare plus other services as well as tourists depend on this Ferry service. Although ferry services are crucial, their frequency and capacity seem inadequate and this tend to make them overcrowded especially during peak hours and the summer season. The timetable comes across as a hurdle for the elderly folk and disabled who depend on ferry transportation, more so for individuals who do not own a car and cannot afford to pay for such infrequent transport means (Bowen Island Municipality, 2020).

Local Roads And Access

Almost all of the major roads on Bowen Island are relatively narrow and winding due to its low volume of traffic. Being a small island, Bowen island does not have an extremely large road network.

There are few major roads connecting different areas of the island, and still a number of zones, particularly those located further from the centre of the island, are more difficult to reach. While those roads are beautiful, they also become dangerous, especially for pedestrians and cyclists. Cycling lanes are virtually unpresent, and the roads sometimes do not have pavements, making it unsafe for the residents, particularly the from the elderly to families with young children (Bowen Island Municipality, 2020).

2. Local Transportation Options

Public Transit

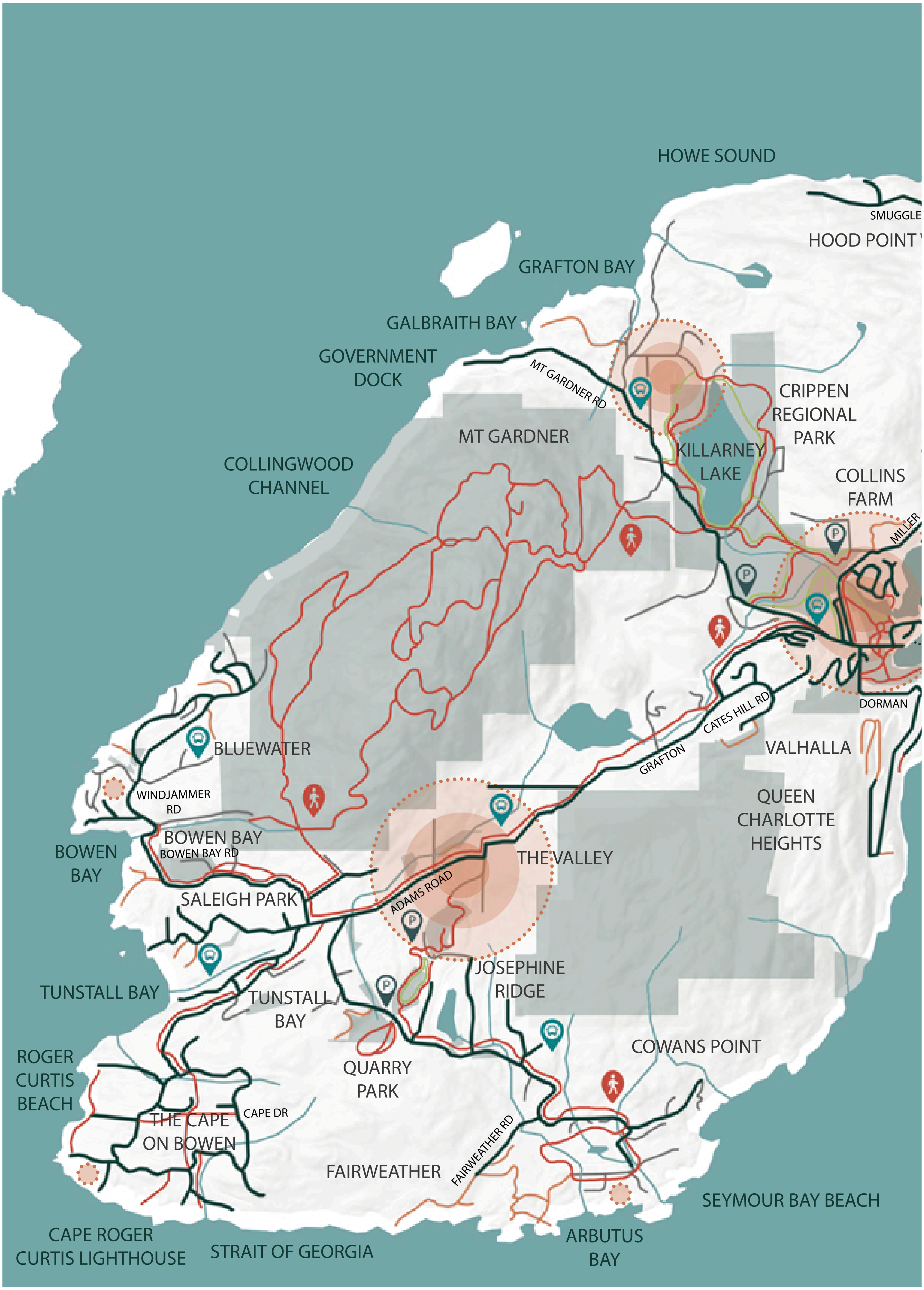
Bowen Island has limited public transport which is offered towards the area, which is few and does not provide a network of local travel areas. The bus service that exists is sparse, and most lands of the island are not well-connected by transit apart from the ferry which brings residents and tourists alike to the island. This puts the majority of residents, especially those who do not own a car, in a position of walking, cycling or utilising their own vehicles to accomplish their day to day operations. Elderly and people facing mobility problems tend to find it a chore in pursuing basic needs such as healthcare, shopping and entertaining sites. Increased public transport facilities in the form of extending the buses or applying shuttle buses would help relieve some of these problems especially for the resident (Bowen Island Municipality, 2020).

Further, significant infrastructure upgrades are needed to safely accommodate multifamily housing developments, due to the insufficient or inadequate systems used on the island, such as on-site wastewater management systems and groundwater supply systems, that are not able to support new higher density residential areas. In general, many of the services that would significantly benefit the lives of older adults are only partially available on Bowen Island. Community services are limited but adequate, with basic healthcare facilities in the form of clinics and a wide range of recreational activities geared toward an active and healthy lifestyle.

At the same time, especially concerning specialized medical care, residents heavily rely on proximity to Vancouver, which complicates access, particularly for an aging population. Similarly, while the variety of recreational activities is diverse, the lack of establishments specifically aimed at older adults, such as wellness centers or educational programs, significantly reduces opportunities for social interaction and support for this demographic. Improving the quantity and quality of these services would greatly benefit this population, but would likely require significant investment and other logistical challenges. One of the biggest challenges on Bowen Island is access to housing.

The island is dominated by expensive single-family homes, which restrict root options for post-parental adults with limited incomes. The lack of affordable multifamily housing forces many individuals to remain in larger homes than they need or want, reinforcing the rental market and limiting opportunities for people at different life stages. Introducing affordable multifamily housing on the island would address this issue, but it may require extensive changes to urban planning and possibly negotiations with the community. In conclusion, Bowen Island presents a variety of challenges and opportunities for the development of affordable and energy-efficient family housing for post-parental adults.

Bowen Island, with its picturesque landscapes and rural setting, presents unique challenges and opportunities related to mobility. As a small island community, transportation options are limited, and these limitations affect residents' ability to access services, work, and recreational activities. The following analysis explores the current state of mobility on Bowen Island, fo¬cusing on transportation infrastruc¬ture, roads, and overall connectivity.1. Transportation InfrastructureA. Ferry ServicesThe primary means of access to and from Bowen Island is the ferry system, connecting the island with Horseshoe Bay on the mainland



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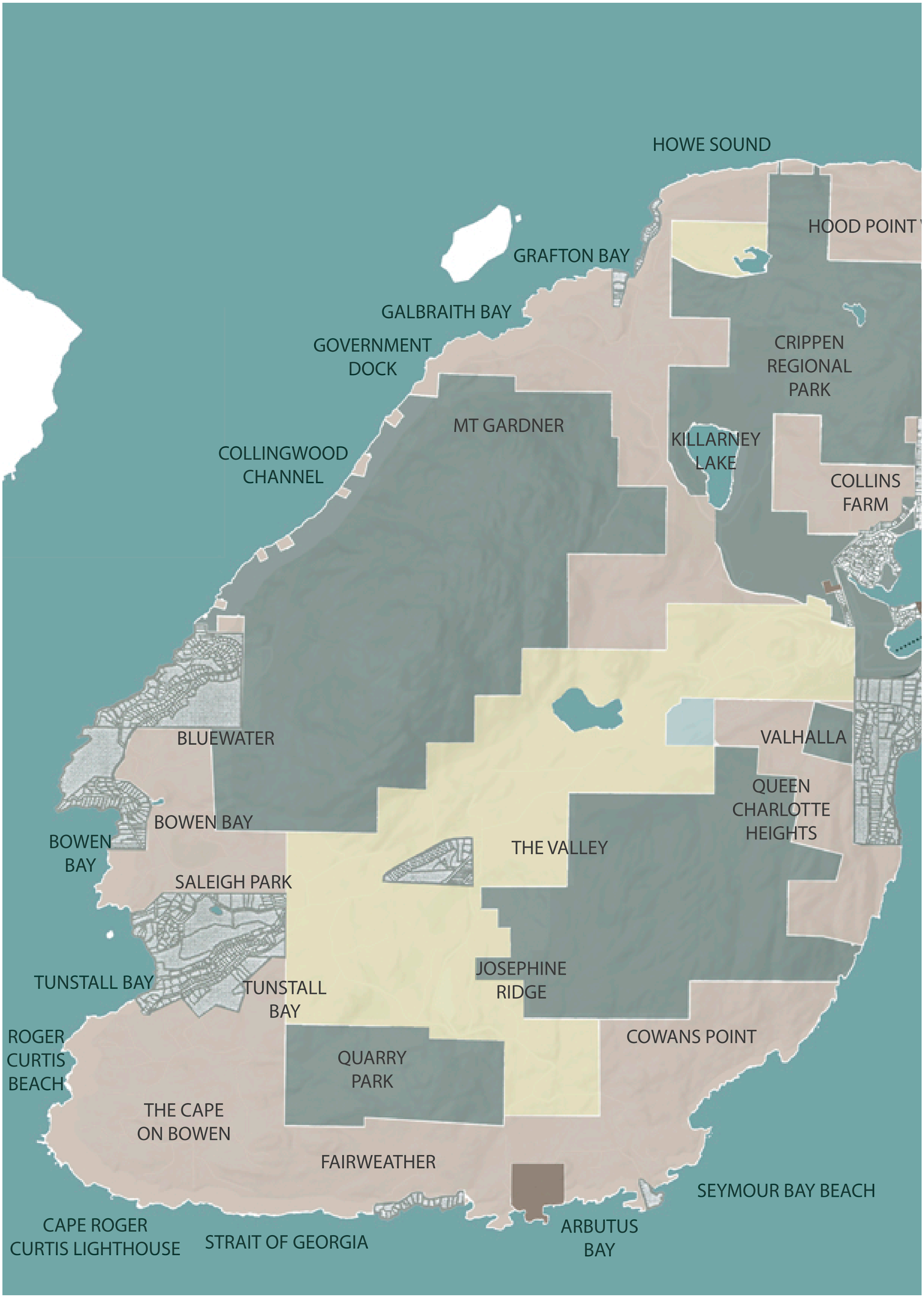
CATES BAY
RS COVE RD
HOOD POINT
WEST
EAGLE CLIFF
EAGLECLIFF
SCARBOROUGH
SNUG COVE HORSEHOE BAY FERRY
DEEP BAY
SNUG COVE
DORMAN BAY
VANCOUVER
QUEEN CHARLOTTE CHANNEL



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CATES BAY
WEST
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SCARBOROUGH
SNUG COVE
HORSEHOE BAY FERRY
DEEP BAY
SNUG COVE
DORMAN
BAY
VANCOUVER
QUEEN CHARLOTTE
CHANNEL

Public Institutions and Water Protection
As shown in the territorial analysis map, Bowen Island zoning is divided into multiple areas. First, the institutional areas, which are the locations of public buildings. Next, water supply and source protection areas are specified due to Bowen Island's strong policies on environmental protection, determining specific areas for natural site protection. Then, there are personal care institutions such as nursing homes and assisted living centers.

Rural Areas & Settlements
Moving forward into other land uses, the Rural Comprehensive-1 zones are intended to be a mix of agricultural and residential uses, allowing for rural living while supporting farming activities. This zoning ensures the preservation of the island's agricultural heritage. Additionally, the Rural Industrial zones accommodate industrial activities of a rural character. Finally, the Rural areas are primarily agricultural and low-density residential areas, emphasizing the preservation of open spaces and the rural landscape. This zone supports farming, horticulture, and residential living with a focus on sustainability.

On the other hand, some senior citizen residential areas which are meant to answer their specific needs are mentioned in the Bylaw but not fully applied. Finally, Settlement Residential, which is what the project lot belongs to. These are the primary zones for residential development on Bowen Island, accommodating single-family dwellings and other housing types. This zone is crucial for addressing the housing needs of the island's population and promoting diverse living options.

Making an emphasis on the housing areas of Bowen Island, the most significant are the Settlement Residential areas. These areas are designed to offer various housing options to meet the needs of different demographic groups, contributing to the island's population growth and diversity. On the other hand, Rural zones are also part of the housing areas in Bowen Island. Although primarily focused on agricultural and low-density residential uses, these zones also contribute to the island's housing supply by offering rural living options. The preservation of open spaces and agricultural activities in these zones ensures a balanced and sustainable approach to development.

Settlement Residential Zones (SR1 and SR2)

In the Bowen Island Municipality Land Use Bylaw, Settlement residential zones are divided into two different sections (SR1 and SR2). In terms of uses of the land, buildings and structures, both zones have similar regulations. The difference between these two is that in an SR2 zone use of the land like kennels or stables is not permitted and it is reserved strictly for dwellings.

Principal Uses of Land, Buildings and Structures	**SR 1**	**SR 2**
Dwelling	♦	♦
Stable	♦	
Kennel	♦	
Accessory Uses of Land, Buildings and Structures		
Uses accessory to *principal uses*	♦	♦
Mini-storage on lots 1 ha and larger	♦	
Home Occupation Use subject to Part 3	♦	♦
Accessory Residential Use	♦	♦
Residential Guest Accommodation	♦	♦
Domestic Agriculture	♦	♦
Permitted Buildings and Structures		
Dwelling, Detached	♦	♦
Buildings and *Structures* accessory to permitted *uses*	♦	♦

Bowen Island Municipality Land Use Bylaw No. 5, 2002

On the other hand, uses, buildings and structures in SR 2 Zones must comply with the following regulations regarding size, siting and density:

Lot Coverage	**SR 1**	**SR 2**
Maximum combined *lot coverage* of all *buildings* and *structures* (m^2) calculated as follows: 100 m^2 plus 10% of *lot* area to a maximum of 500 m^2	♦	♦
Number of Units and Site Areas		
Maximum number of primary *dwellings* on any *lot*	1	1
Maximum number of accessory *buildings* on any *lot* for each 0.2 *ha* of *lot* area or portion thereof, plus one, subject to Part 3	1	1
Maximum number of accessory *buildings* on any *lot* that may be used for *home occupation* for each 0.2 *ha* of *lot* area or portion thereof	1	1
Height		
Maximum *height* of a *building* or *structure* (metres)	9	9
Setbacks		
Minimum *setback* from side *lot lines* (metres)	3	3
Minimum *setback* from the front and rear *lot lines* (metres)	7.5	7.5
Minimum setback for a building from any lot line that abuts a highway (metres)	4.6	4.6

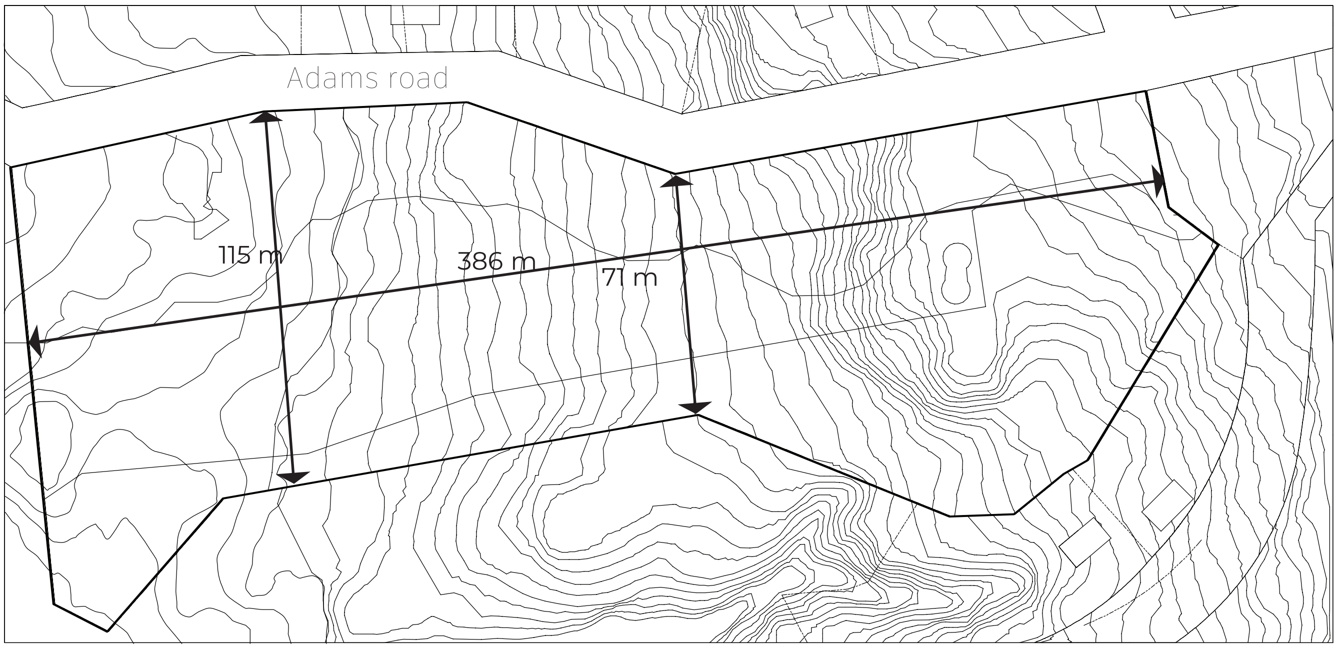
Bowen Island Municipality Land Use Bylaw No. 5, 2002

This gives a clear image of how the Bowen Island bylaws are applied on the island and specifically on the project site.

5.Site Analysis

5.1 Lot Characteristics

The lot is located on the west side of Bowen Island, in the Tunstall Bay Neighborhood (SR 2 Zone), specifically on 1473 Adams Road, which is part of the Islands main transportation artery and is 500 meters of other 3 main arteries (Bowen Bay Road, Sunset Road and Tunstall Bay). It is 6.5 kilometers away from the Snug Cove Ferry terminal and 100 meters from public transportation. Lot also has easy access to the main beaches, Tunstall Bay Club and Golf Course.



The lot has an irregular, elongated shape. It is relatively flat, with a bluff area on the northeastern side. The total elevation change for the lot is 40 meters. Approximately 75% of the lot is below the bluff, which means that three-quarters of the land in question lies at a lower elevation compared to the rest of the area, specifically below a steep cliff or embankment. The elevation change is 9%, indicating that the slope of the land changes by 9% from the high point to the low point. For instance, if you travel 100 meters horizontally, the elevation would change by 9 meters vertically. At its narrowest portion, the lot measures 71 meters wide, while at its widest points, it measures 386 meters. The total lot area is 10 acres (4.04 hectares).

5.2 Environmental Analysis

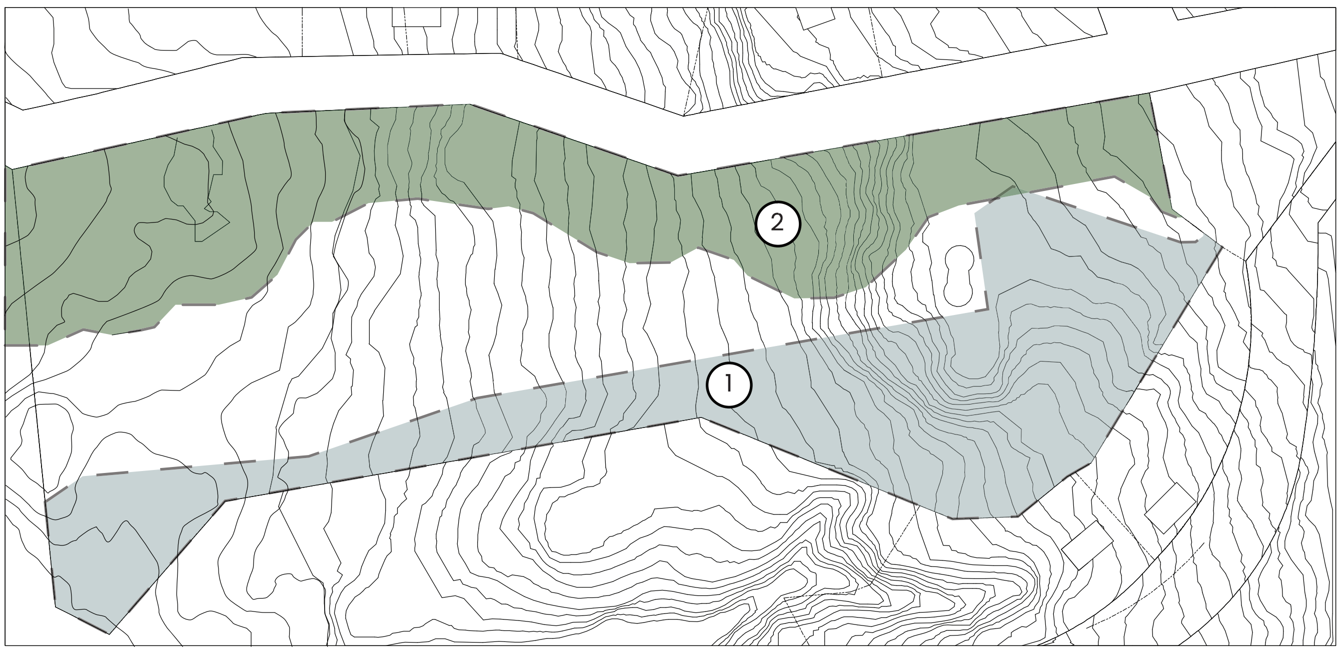
In terms of solar exposure, the lot has a south-facing orientation. Combined with the slope, this represents an opportunity to create a project that leverages natural sunlight as a tool.

Buffers, Wetlands and Protected Areas

The lot contains two different environmental buffers. These buffers are restrictions on construction to avoid a negative impact on the natural environment of the island. The first buffer is located along the northern part of the lot; it is set to avoid any disruption of the stream water that runs through this area. This area can be intervened, but it must be justified with the least possible impact. On the other hand, the southern area of the lot has a buffer that is set to protect the small stream that passes through the lower area and the wetlands located inside the lot. This area is set as a development boundary, and it is not permitted to construct here.

Also, the lot has two different wetland areas. One is located in the southeastern part of the lot, which is protected by a development buffer. The other is located in the northwestern part of the lot and has a 30-meter distance restriction for building nearby. These are the main constraints found in the lot in terms of building location.

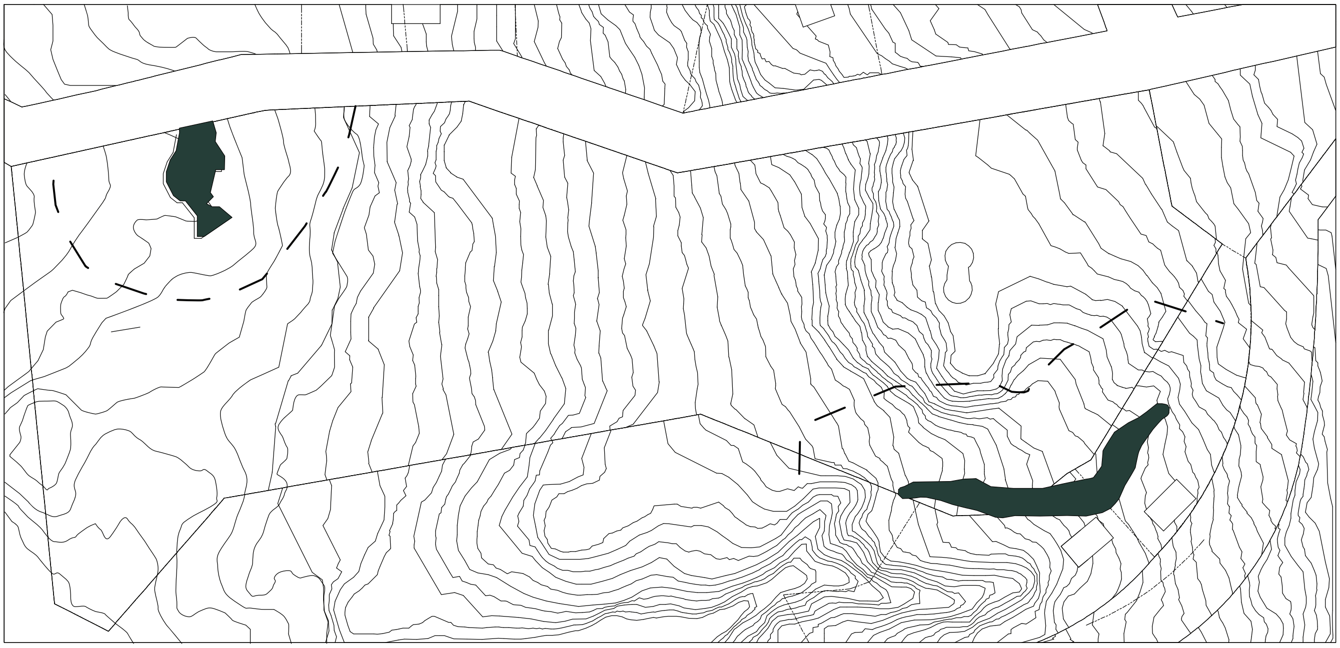
Buffers



Both of the buffers fall under the categories of watershed, aquifer, and streamside protection. This takes into account the wetlands, streams, and subterranean water that pass through the lot..

Wetlands

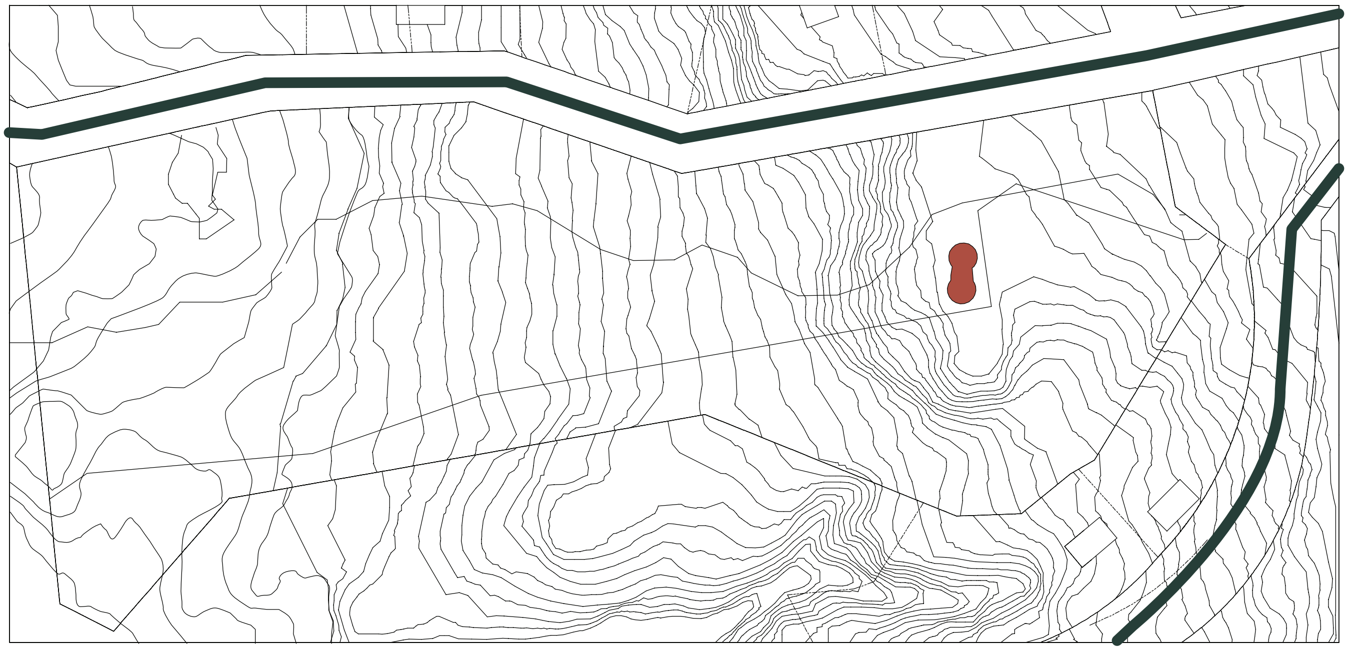
All of the wetlands need to have a minimum 30-meter distance protection in order to preserve them.



Vegetation

One of the lot's main characteristics is its vegetation. As this lot hasn't been touched in over a hundred years, the trees are one of its greatest assets. These trees, from different species, vary in height from 30 to 40 meters. This creates a humid climate closer to the terrain, given the amount of shade they cast, especially when combined with the wetlands.

Main Roads and Existant House



Vehicular Access Main Roads

Adams Road is the main street that crosses the island from east to west. This road represents an opportunity as the main public transportation on the island circulates through here. On the other hand, a preexisting small house is located in the upper area of the lot.

Path and Trails

The house has vehicular access from Adams Road. Additionally, it was discovered that an old trail from the dynamite industry that used to exist on the island passes through the lot.







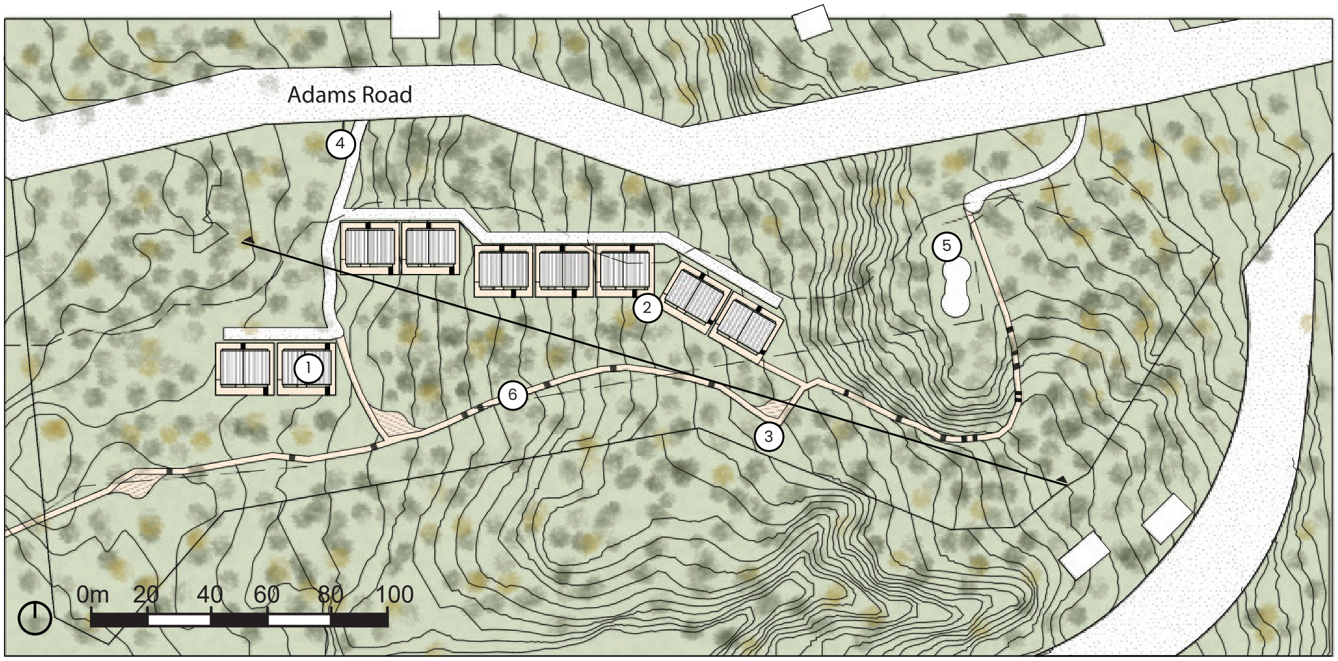



Photos taken by the local engineer (Julian Barrera)

03

The Project

Project Master Plan



(1) Housing Units (2) Inner Paths (3) Public Meeting Area

(4) Car Access (5) Exsiting housing Unit (6) Public Trail

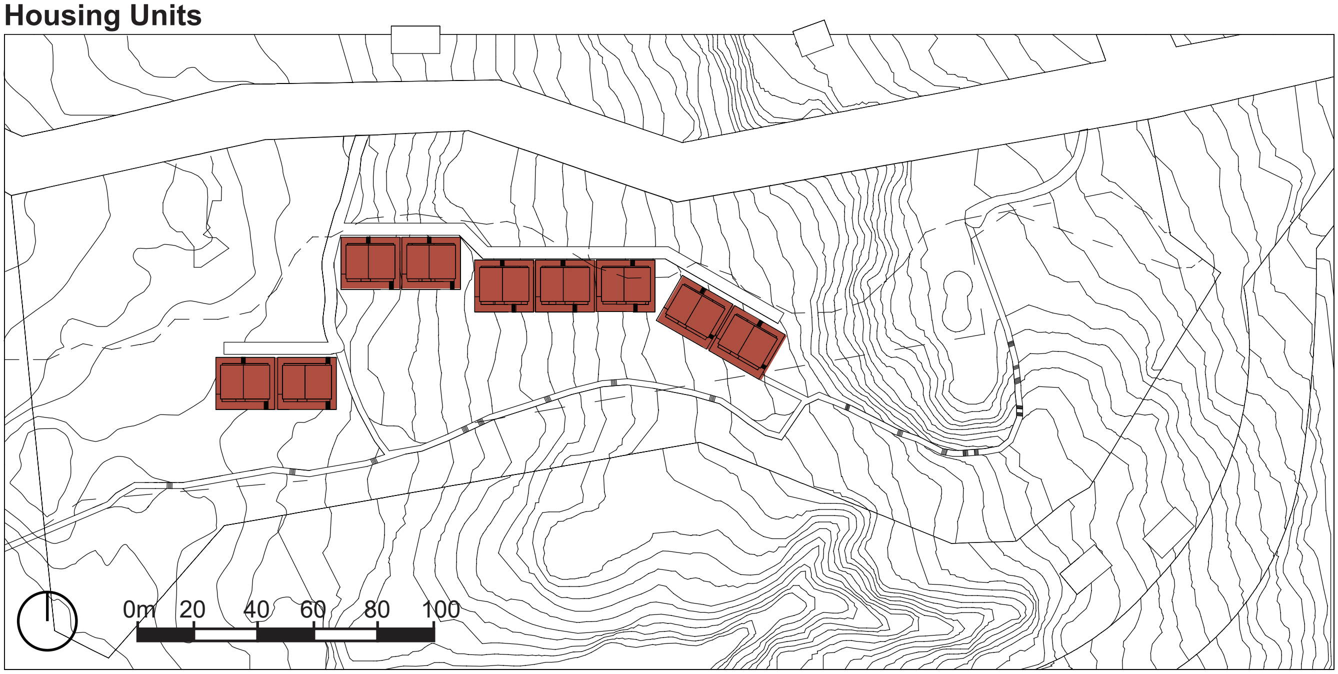
Among the main components of the master plan are the old dynamite trails integrated into the project (2), nine triplex housing units placed on the terrain without harming the environment (9), and public meeting areas along the paths in the southern part of the lot (3). Starting with the main access (4), it is located on the northwestern side of the lot. The nine housing units are situated in such a way that they respect the development buffers of the lots and the natural environment within it.

The area where the housing units will be placed is located along the lower portion of the lot, which has an average slope of 15%. These housing units have a height difference of around 1 meter and a minimum separation of 6 meters between houses. Additionally, the housing units are both shaped and positioned in a way that they do not interfere with the preexisting natural environment and maintain privacy within the volumes.

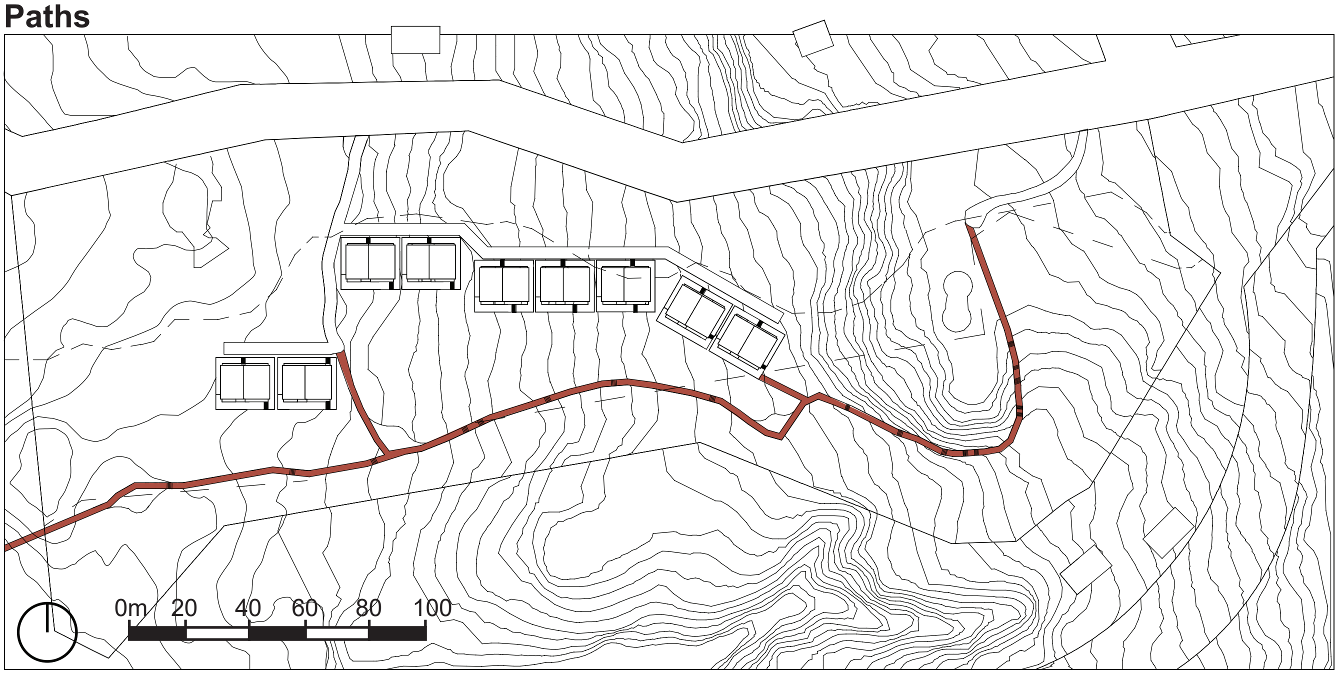
Housing Units and Paths

The 9 housing units are located on the terrain based on the different characteristics of the lot. First, the two environmental buffers located in the northern and southern parts of the lot provide a specific zone available for building without any environmental restrictions. Also, the old dynamite trail provides the project with the main vehicle access and connects Adam Road with the public space inside the project.

Housing Units



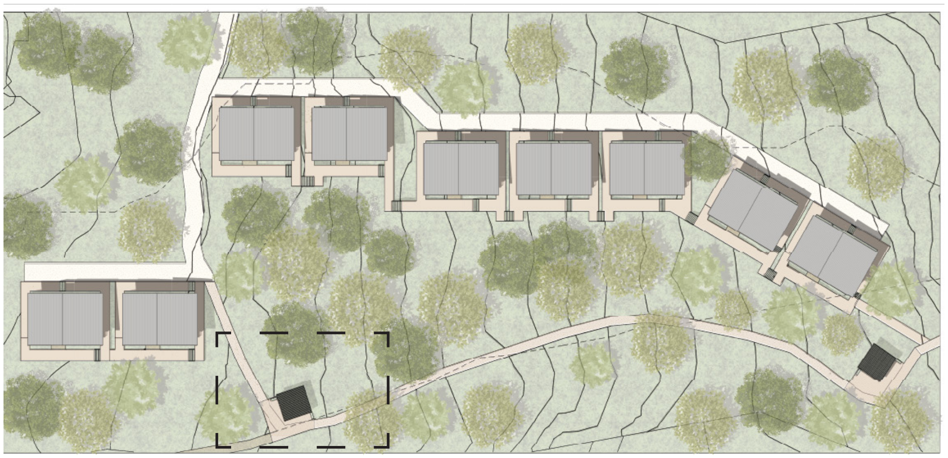
Paths



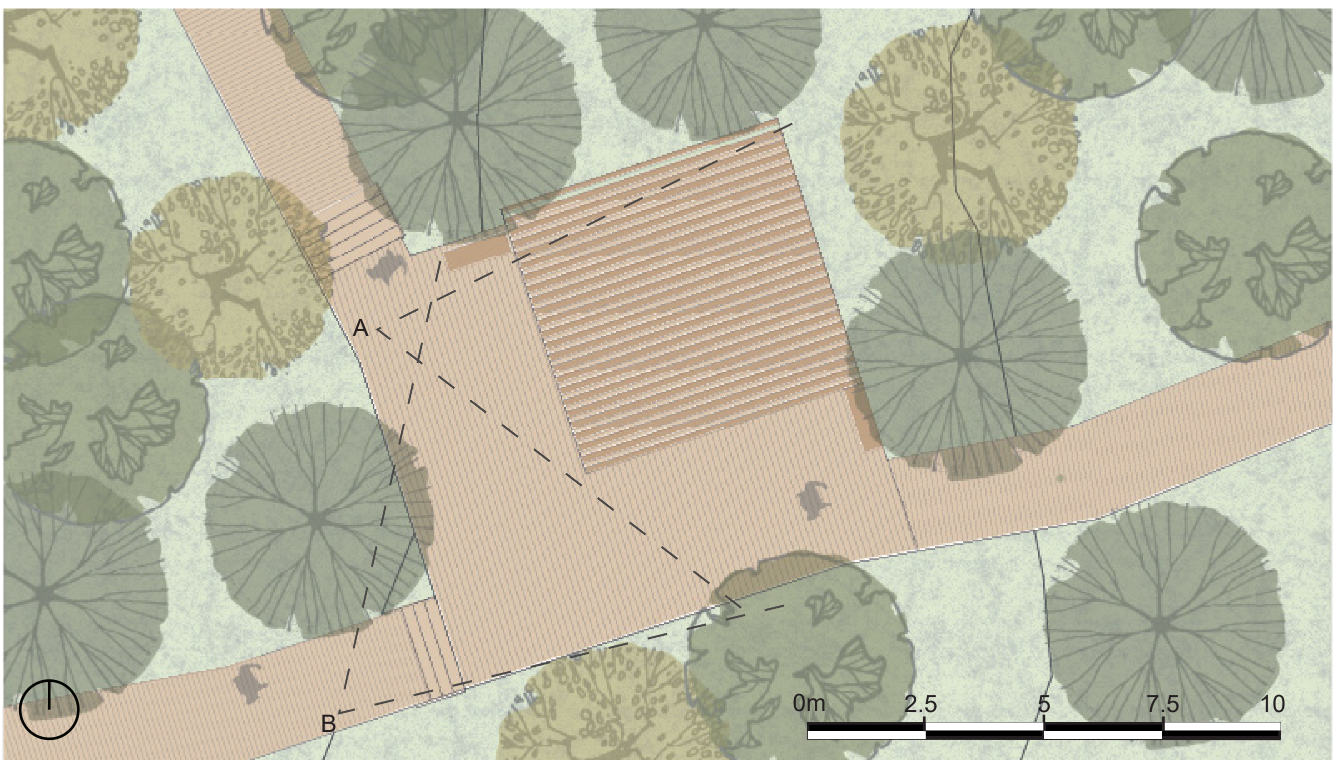
Common Areas

One of the objectives of the project is to revitalize the old dynamite quarry trails by turning them into ecological pathways for sightseeing. One way to achieve this is not only by providing the island with this public space, but also by connecting the proposed housing units to this track.

Resting points are located along the path to create meeting points that are surrounded by nature. These points are situated in areas where the vegetation is denser. In terms of materiality, wood is the most accessible material in British Columbia and the Vancouver districts.



This point is composed of a covered area for sun or rain protection, benches and tables for picnics or shared activities, and a deck for sightseeing or open space activities.



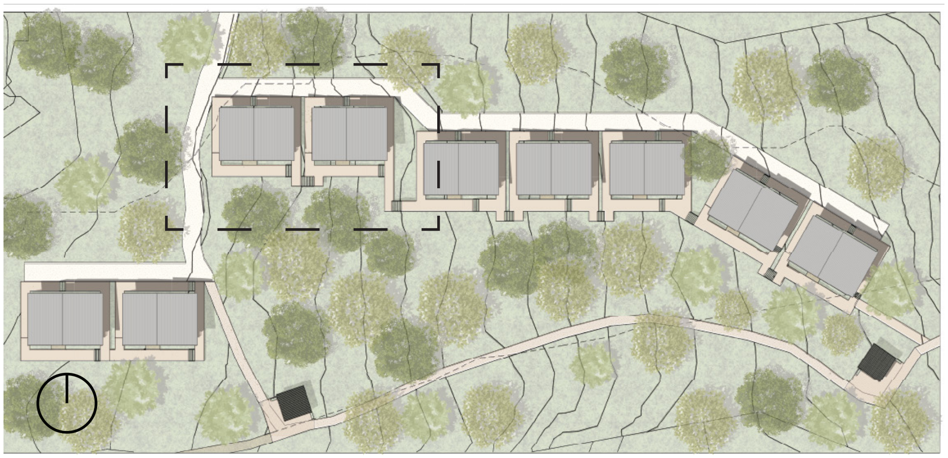
Renderings Path & Meeting Areas

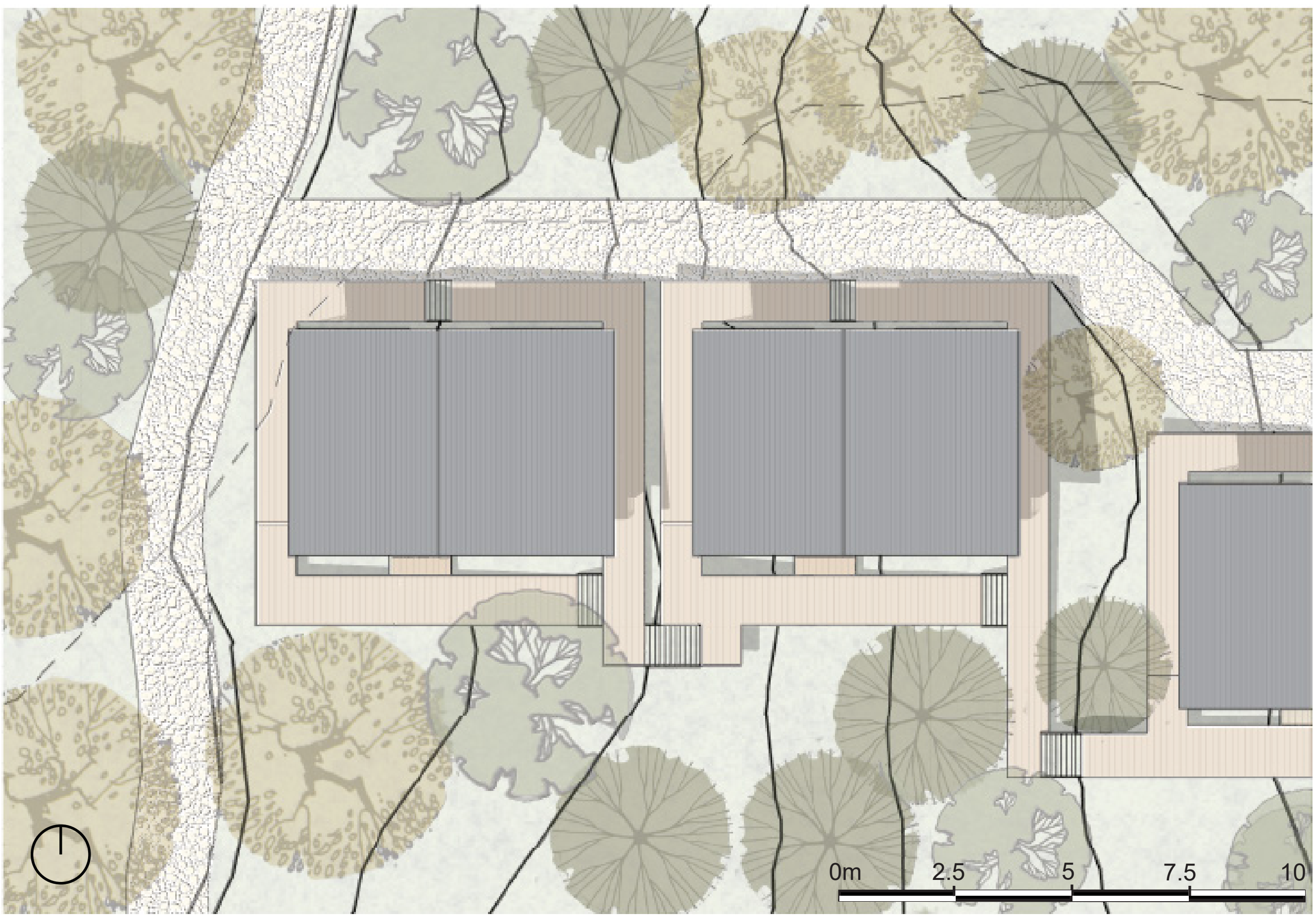
Rendering A

Rendering B

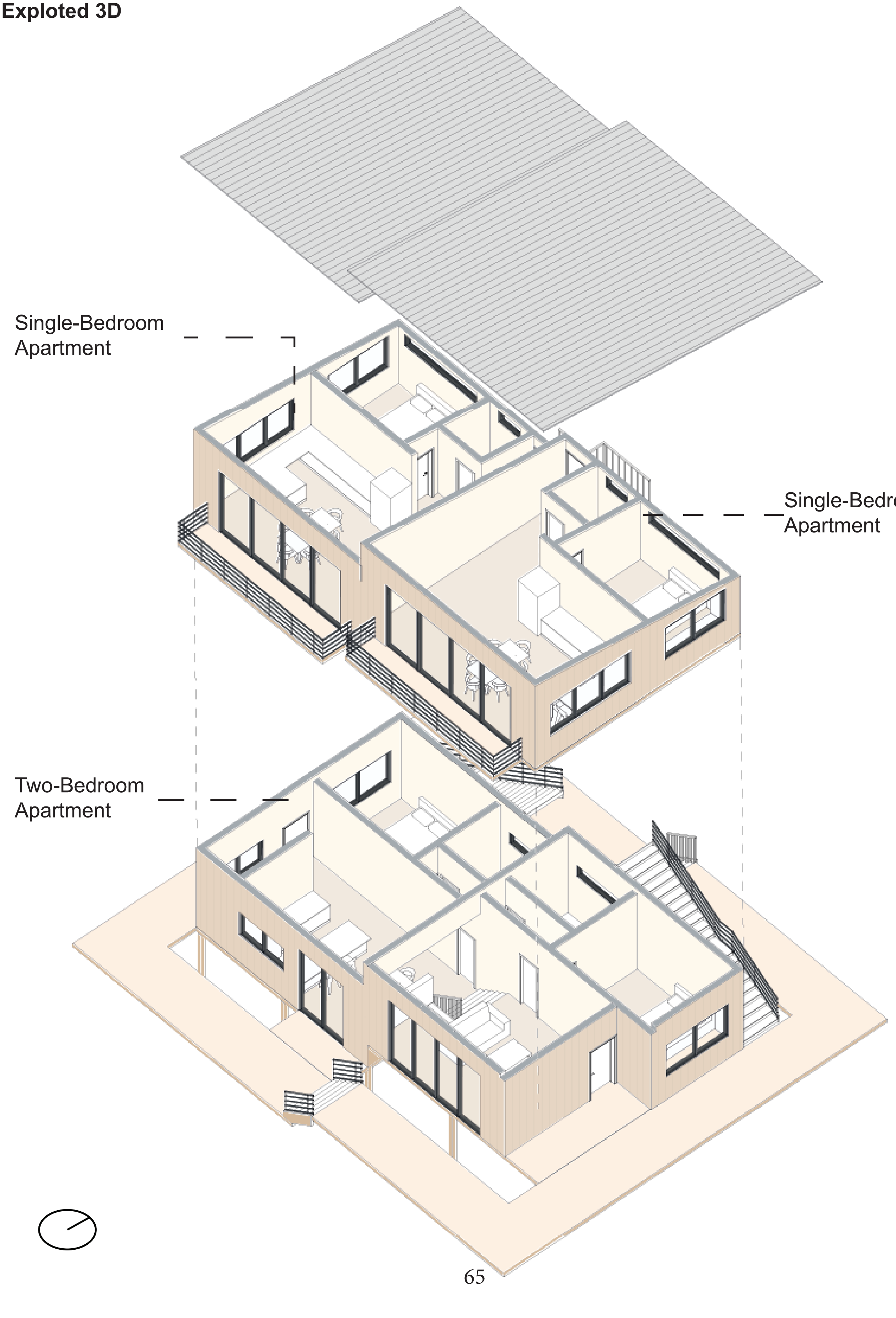
Housing Units

Housing units are placed towards the central area of the lot to respond to multiple factors such as development buffers and environmental constraints. The volumes are south-oriented and have an inner circulation between them that connects the project with the public area via walkable pathways.





Exploted 3D


Single-Bedroom
Apartment
Single-Bedroom
Apartment
Two-Bedroom
Apartment

The housing unit is composed of three apartments that address the needs and market gaps identified in the investigation. First, on the lower levels, there is a two-bedroom apartment that caters to the island's population looking to downsize. This segment includes empty nesters and elderly adults seeking affordable housing units.

On the other hand, two single-bedroom apartments cater to younger adults and local workers who are looking for affordable housing without the necessity of leaving the island. This represents an opportunity to grow the internal economy of the island from the workers' point of view, as it won't be necessary for them to move out, thereby generating a workforce within the island. From the younger adults' point of view, it's an opportunity to diversify the population since the current supply in the housing market consists of family-size houses, which drives younger adults to move out of the island.

In terms of external circulation of the housing unit, private paths are proposed around the perimeter of the house. These paths are meant to be elevated from the ground and connect to the public paths in the southern area of the lot. The access for the lower apartment is located on the eastern façade, while the access to the upper-level apartments is located on the northern façade.

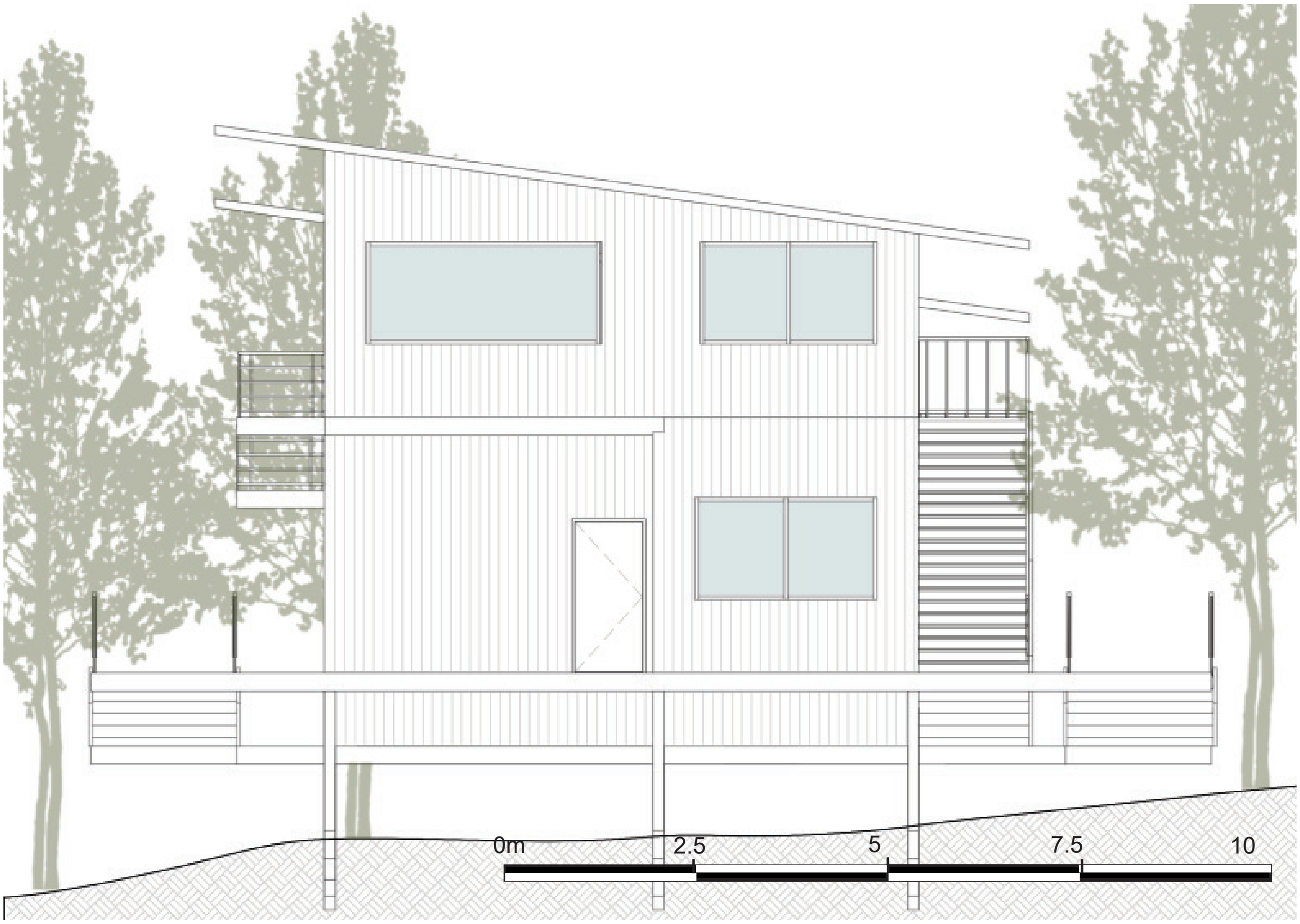
There are multiple sustainability strategies applied to the housing unit. One of them is the use of local materials such as wood for both the structure and finishes of the building. This reduces the carbon footprint of the building and increases its efficiency. Additionally, the volumes are set to be elevated, not only as a performance strategy but also as an environmental strategy to protect the terrain. On the other hand, insulation and airtightness are important factors in the volume, since one of the main objectives is to achieve affordability in terms of energy consumption. Ensuring a good application of these strategies represents optimal energy efficiency given the climatic conditions of Bowen Island.

South Elevation

One of the strategies used for energy performance in the building is the south-oriented implantation. This means projecting the volume and activities towards the south to utilize the solar exposure available on the terrain. In this case, the southern façade features openings for the social activities of the apartments. On the lower level, the apartment has the living room in the eastern area and the kitchen and dining room in the western side. The kitchen and dining area has a sliding double-glazed door facing south and a smaller window on its side. The living room has a large window with a height of 2.7 meters. On the other hand, the south façade of the upper levels incorporates balconies that serve as shading devices for the lower level. These balcony doors are also double-glazed sliding doors with a height of 2.7 meters.

The housing unit volume is shaped with the elevation of the terrain. The average slope of the terrain in the location of the houses is 15%, meaning the terrain descends 15 centimeters every meter. Knowing this, the volume of the house is segmented into two halves split perpendicularly to the slope. On the other hand, the volume opens towards the south, providing this facade with greater exposure to sunlight in the winter. In the summer, a small overhang is applied, but the trees in the terrain already serve as a natural sunlight filter due to their height.

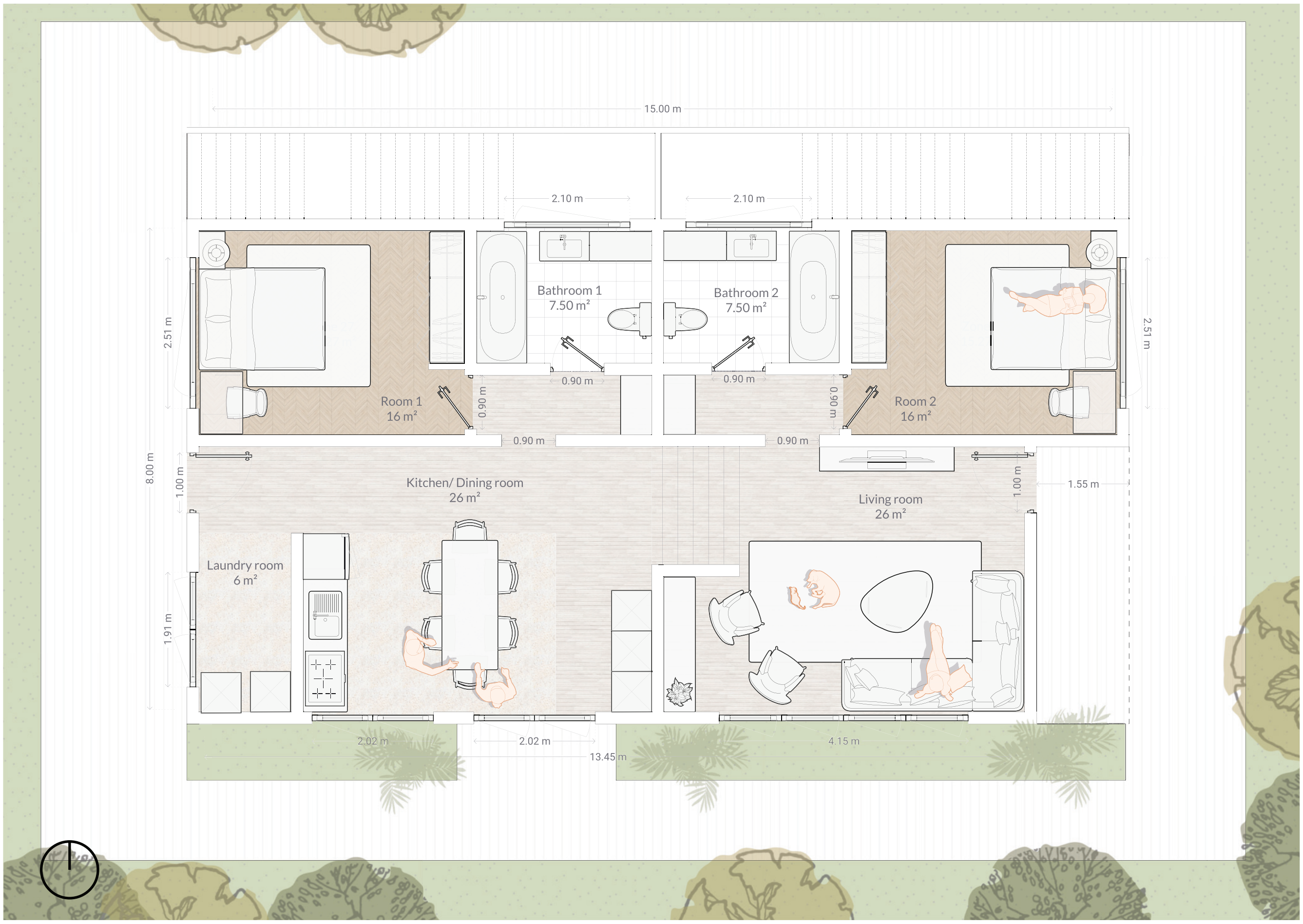
East Elevation



The eastern façade comprises the main entrance of the lower-level apartment. The lower apartment has just one window facing east, which belongs to the main bedroom and is one meter high. The same window is used on the opposite façade for the secondary room. On the upper level, the east façade includes a window for the kitchen and dining area, and another window for the bedroom towards the northern side.

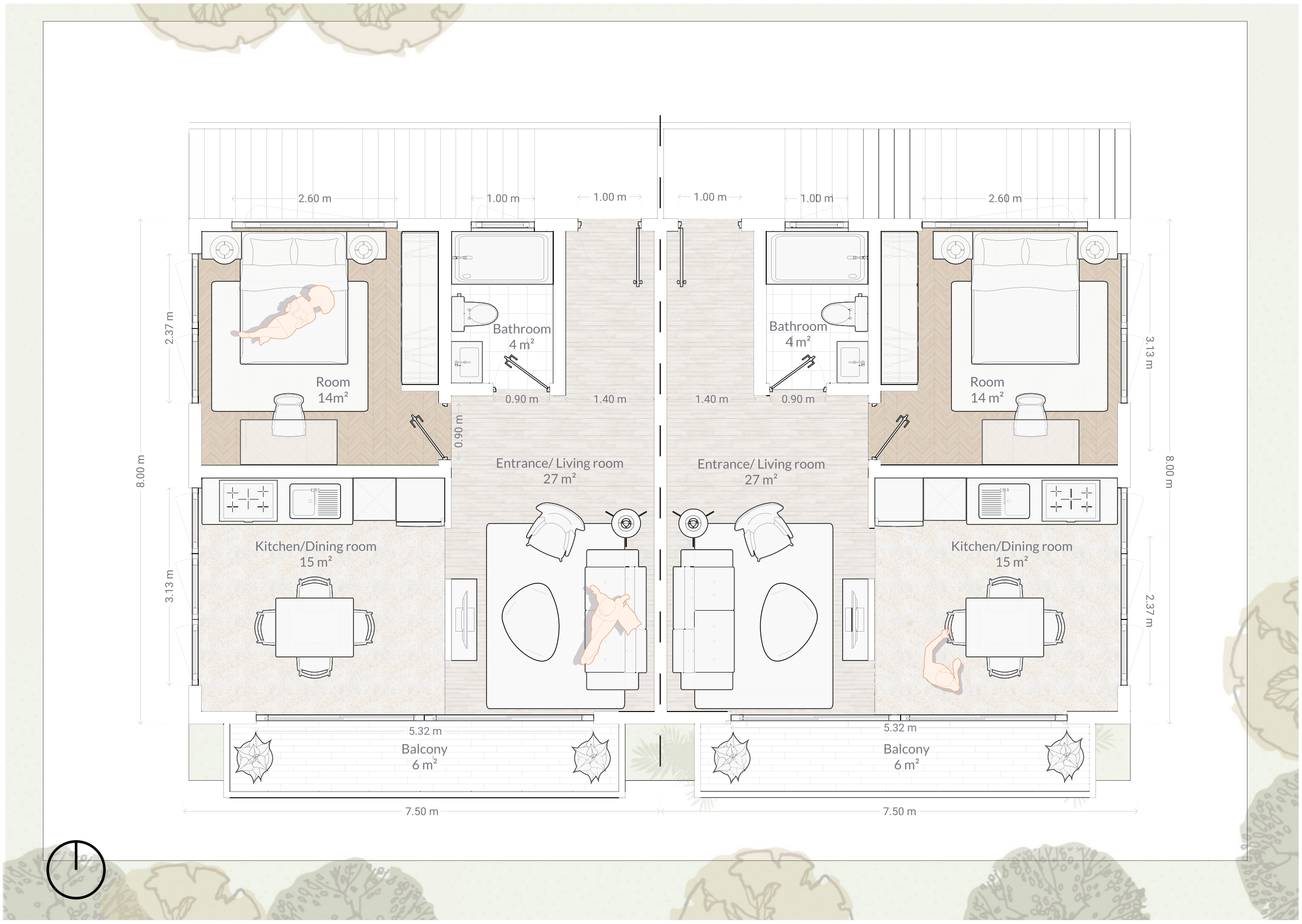
On the other hand, circulation is designed to go all around the volume. In the northern part of the volume, there is a private entrance for residents through a set of platforms that are intended to reduce the impact of the houses on the natural cover of the lot. In the southern area, the common pathways connect with the public paths in the lower area of the lot.

Two-bedroom Apartment



The first apartment has a total area of 105 square meters and a ceiling height of 3.2 meters. It is composed of two different levels with a 1-meter height difference and has two bedrooms. The main bedroom, towards the northeastern side of the apartment, has an area of 16 square meters and a hallway connecting to its 7.5-square-meter bathroom. On the other hand, a secondary bedroom located towards the northwestern area of the apartment has similar dimensions to the main one. This room's activities can vary depending on the user's desires and it also has a private bathroom. Towards the southern facade, the social activities of the apartment are located. On the eastern side, the living room, with a large 4-meter-long window facing south, is elevated one meter above the kitchen and dining room area. The kitchen and dining room, also 26 square meters, have both a sliding door and a small window facing south. Finally, the laundry room is located towards the southwestern area of the building, works as a secondary entry, and has a mudroom function as well.

One-bedroom Apartments



The upper-level apartments are composed of three spaces. First, the bedrooms located towards the north part of the building with an area of 14 square meters. Then, the 4-square-meter bathroom located by the apartment access serves both the social area of the apartment and the bedroom. Finally, the social area is composed of an open space for the kitchen, dining table, and living room. This area is open towards the south for more exposure and also has a balcony on this side.

The area of this apartment is proposed to accommodate both the younger population who are moving out of their family houses and do not want to leave the island, and single workers on the island who need affordable housing. This approach considers the economic impact of having local workers reside on the island, making it more affordable for them to live there rather than commute.

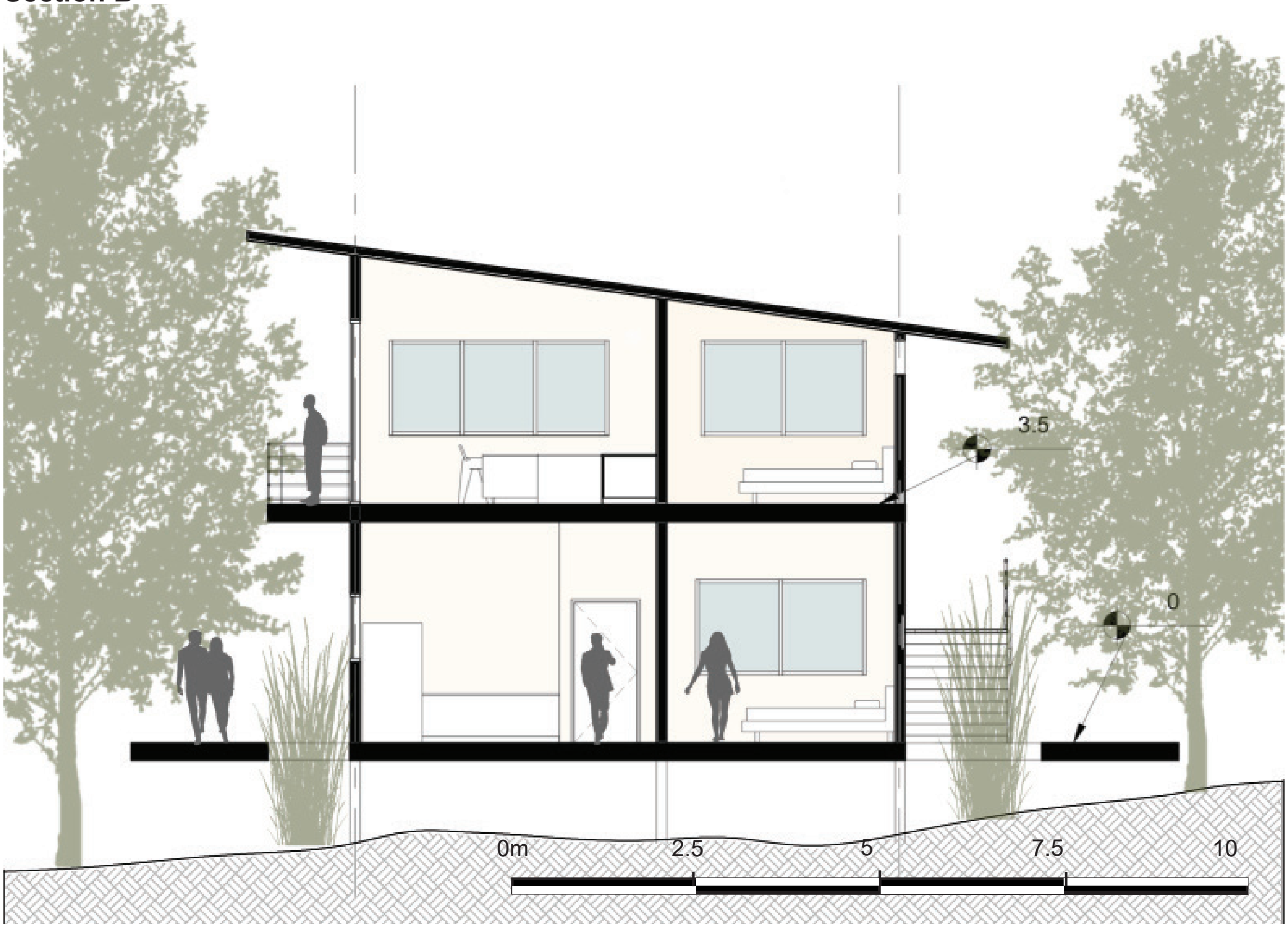
Housing Typologies

Section A

The volume is segmented in the middle by a 1-meter height difference. This is created to adapt the volume to the terrain slope. In the lower apartment, this height difference marks the space between the dining room and kitchen and the living room. On the other hand, the upper apartments are divided by this height change and mirrored along this axis.

Housing Typologies

Section B



In terms of height difference between levels, the second level is 3.5 meters high with respect to the lower level. Additionally, the sloped roof is a strategy for both snow and water management in the project. The highest point of the building, towards the south facade, is 8.5 meters high, taking into account the 1-meter difference in the middle of the volume. The minimal interior height in the upper levels is 2.7 meters, while the maximum is 3.7 meters, projecting the building towards the south for better sun exposure.

4. Energy Efficiency Strategies

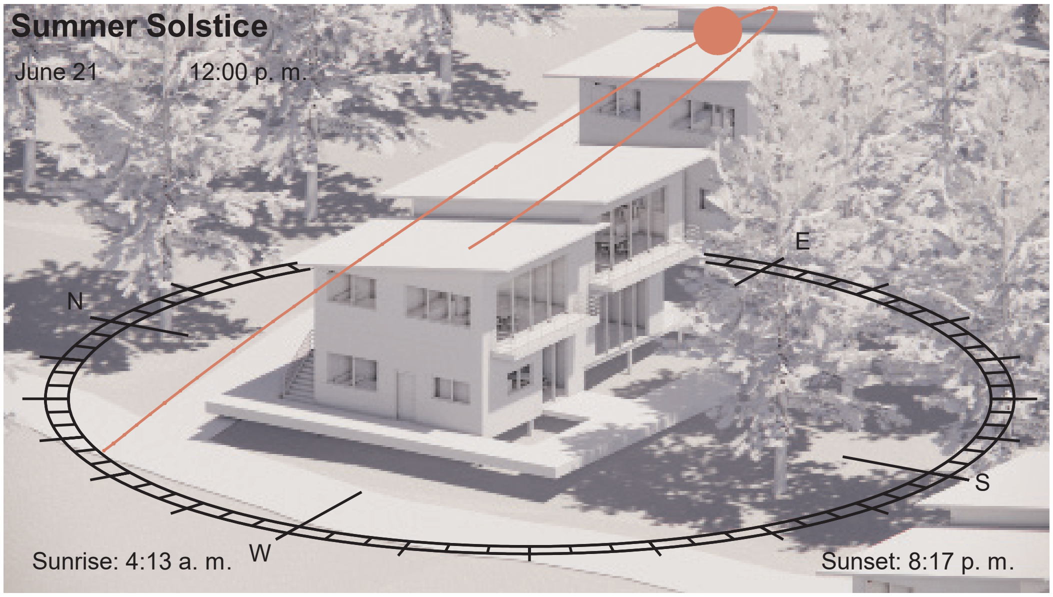
Strategies

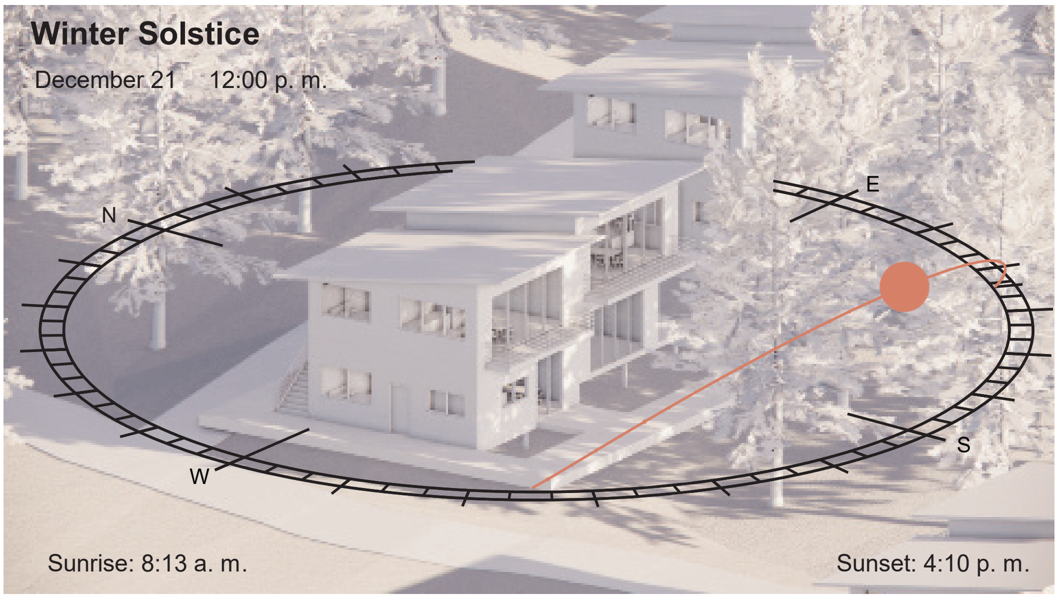
Given Bowen Island’s mild coastal climate with wet winters and cool summers, efficiency strategies should focus on minimizing heating requirements in winter, managing humidity, and maximizing passive solar gains. Among the strategies used in the proposal design were:

1. Southward Orientation: This helps in maximizing passive solar gains, capturing sunlight during the winter to reduce heating needs.
2. Overhangs as Shading Devices: Overhangs are strategically implemented to provide shade in summer, helping in managing indoor temperatures and reducing cooling demands.
3. High-Performance Insulation: The use of high-quality insulation materials ensures that the building retains heat during winters and stays cooler in summers, enhancing energy efficiency.
4. Airtightness of the Building: Ensuring the building is airtight helps in preventing drafts, maintaining a stable indoor temperature, and reducing energy consumption.
5. Renewable Energy Resources: Incorporating renewable energy sources like solar panels or wind turbines in the project can further minimize the building’s environmental impact and reliance on non-renewable energy sources.

These strategies collectively aim to minimize heating requirements in winter, manage humidity, and maximize passive solar gains, making the building more efficient and sustainable.

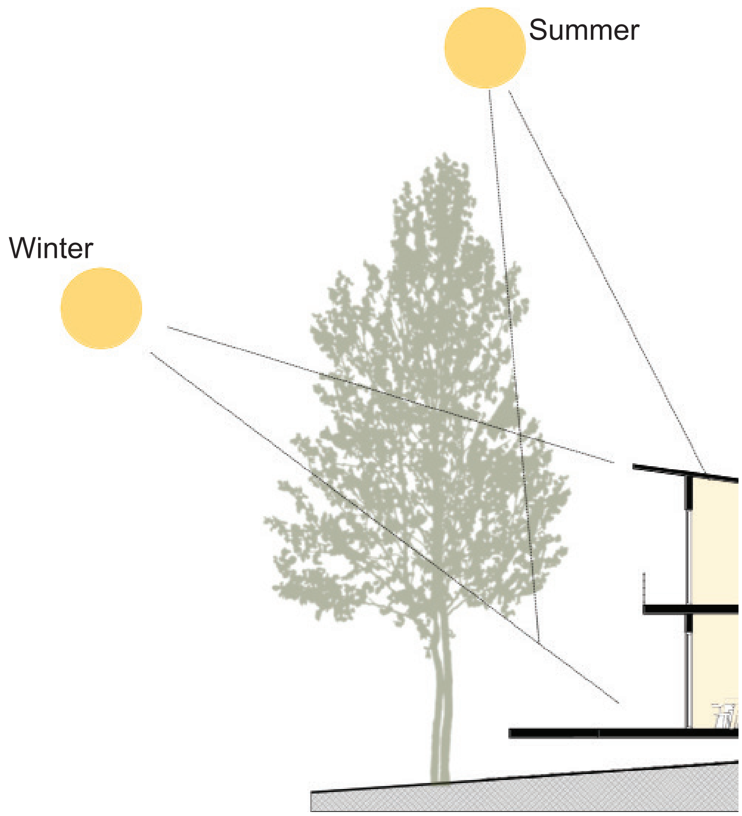
Southward Orientation





By orienting the buildings to maximize southern exposure, the housing units will capture solar heat in winter while minimizing direct sunlight in summer when the sun is higher. This approach will reduce the need for artificial heating during colder months, which is crucial given Bowen Island's cool, wet winters. Additionally, the project lot has an average slope of 15% around the area where the houses are proposed. This provides the opportunity to open the volume towards the south from a higher point.

Overhang & Shading Devices



The angle of the sun at the winter solstice in Bowen Island is approximately 21.2° above the horizon at solar noon. At the summer solstice, the sun reaches an angle of about 68.8° above the horizon at solar noon.

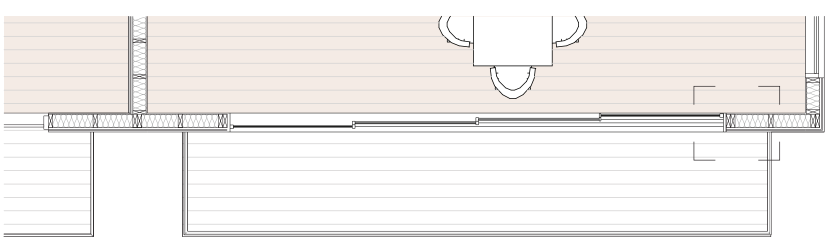
Strategically placed horizontal elements such as overhangs or louvers will help shield the interiors from excessive sunlight during warmer months, while still allowing sunlight during the winter. These shading devices could be designed based on the solar exposition on Bowen Island and tailored to the housing units to balance seasonal variations and reduce costs.

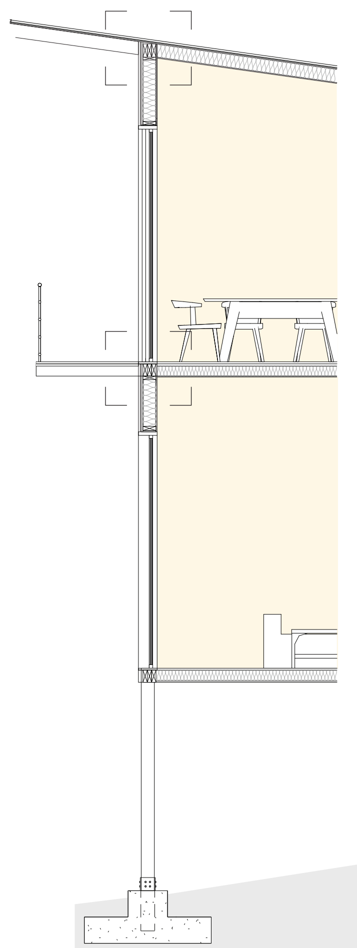
In the proposal, there are two specific shading devices proposed for each volume. First, a room overhang on the southern facade to control exposure on the upper levels. Also, a balcony over the lower levels on the southern facade to protect these areas from sunlight exposure during the summer. On the other hand, given the conditions of the lot, no major shading devices are needed. One of the significant characteristics of the trees that surround the house is their density and height, as they reach an average of 30 meters. These trees also serve as a natural sunlight filter during the hot summer days (Green Building Council, 2021).

Building Envelope

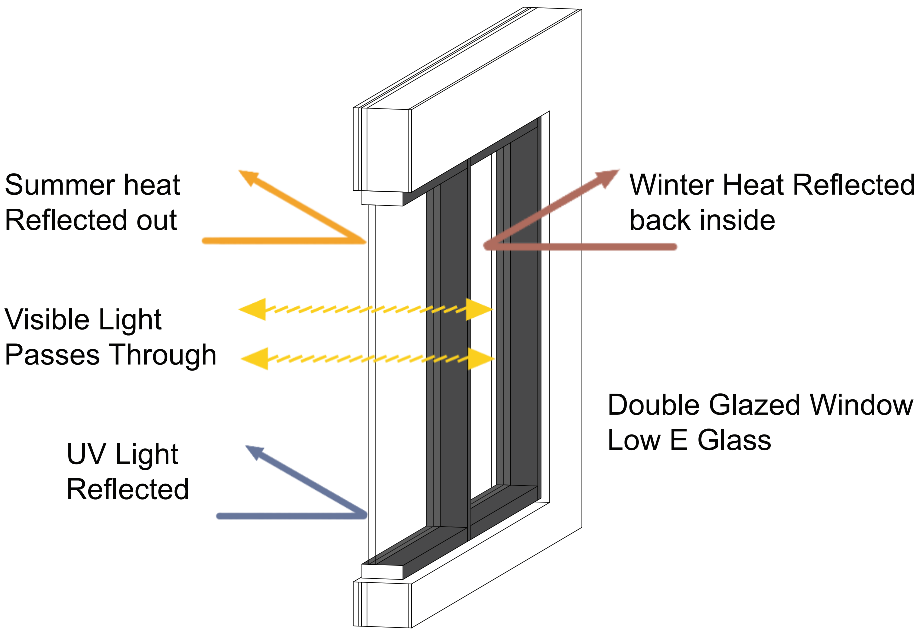
Having a efficient building envelope strategies is important in order to maintain energy efficeindy and comfott within the building. It acts as a barrier between the interior and the exterior of the building. This hepls to regulate temperature, humidity, and airflow. According to the U.S. Department of Energy, an effective building envelope can significantly reduce energy consumption by minimizing heat loss during winter and heat gain during summer. This is achieved through proper insulation, airtightness, and the use of energy-efficient materials. By improving the building envelope, homeowners and businesses can lower their heating and cooling costs, reduce their carbon footprint, and create a more comfortable living or working environment (U.S. Department of Energy, n.d.).

Both window glazing and the opaque envelope are taken into account in the proposal. The windows in the building are low-e double-glazed to control the exposure inside the building. In terms of the opaque envelope, all of its components are considered. The exterior walls, roof, and lower-level floor have the necessary insulation to provide comfort to the user.





Double- Glazed Windows

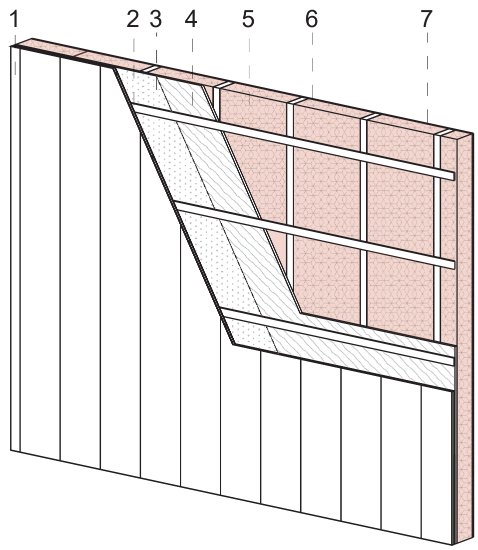


Given the higher humidity and cooler climate, Double-glazed windows with low-E (low emissivity) coatings would provide an additional layer of insulation. Double glazing will enhance thermal comfort, reduce noise (important for island tranquility), and minimize condensation (Green Building Council, 2021).

Double-glazed windows work by filtering the incoming solar exposure. They reflect heat and UV light while allowing light to pass through. Additionally, during the winter, they maintain the heat inside the building, ensuring thermal comfort.

Insulated Housing Envelope

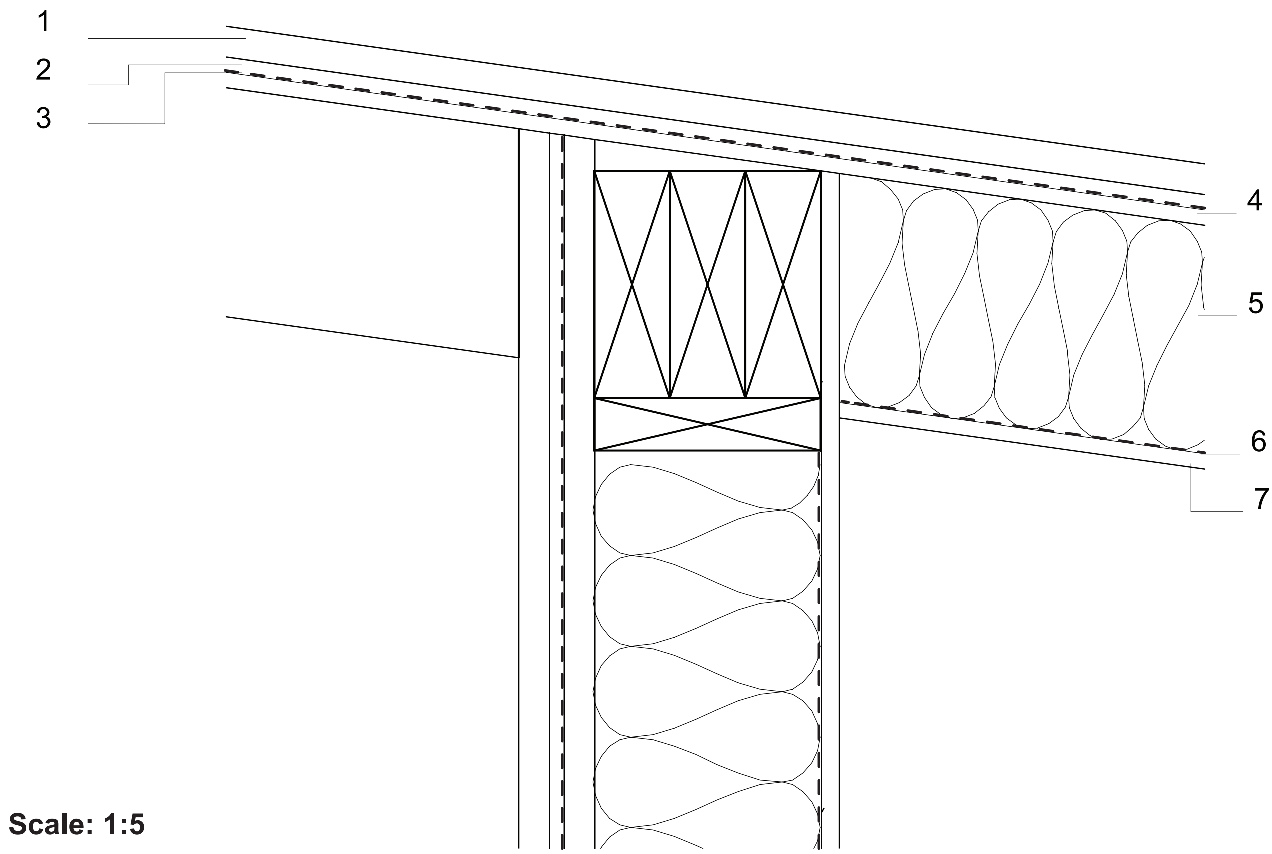
External Walls



1. Exterior Vertical Cedar Siding
2. Horizontal Battens (Siding Support)
3. Waterproof Membrane
4. Wood Sheathing
5. Insulation & Vertical Sturctural Studs
6. Vapor Barrier
7. Gypsum Drywall Finish

To address the island's damp and cool climate, high-quality insulation (such as spray foam or rigid foam panels) can be used in walls, roofs, and floors. A well-insulated housing envelope reduces heat loss, which is essential for minimizing heating needs and maintaining consistent indoor temperatures in the rainy, cooler months.

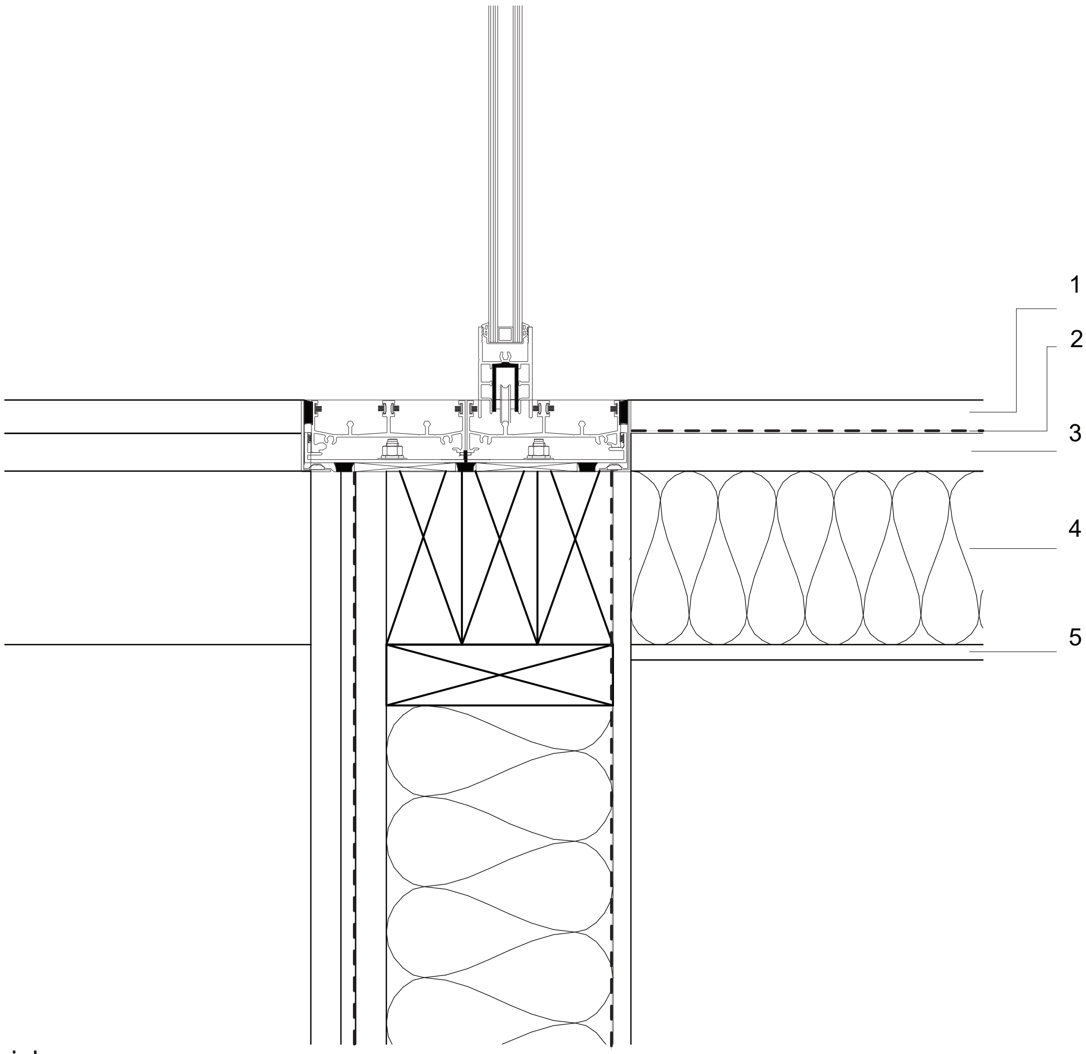
Roof Detail



1. Metal Roof
2.Wood Battens & Air gap for Ventilation
3. Waterproof membrane
4. Wood Sheating
5. Insulation
6. Vapor Barrier
7. Wood Ceiling Finish

The roof is composed of seven different layers. First, the metal roof finish. Then the wood battens or studs, which hold the metal roof and provide ventilation under the roof to avoid humidity problems. Next, the waterproof membrane, also known as building wrap, which goes around the whole building. Then, the wood sheathing, which protects the thermal insulation of the roof and prevents any water leaks. After that, the insulation, which is meant to maintain both airtightness and thermal comfort in the house. Finally, the vapor barrier and the internal ceiling finish.

Floor Detail

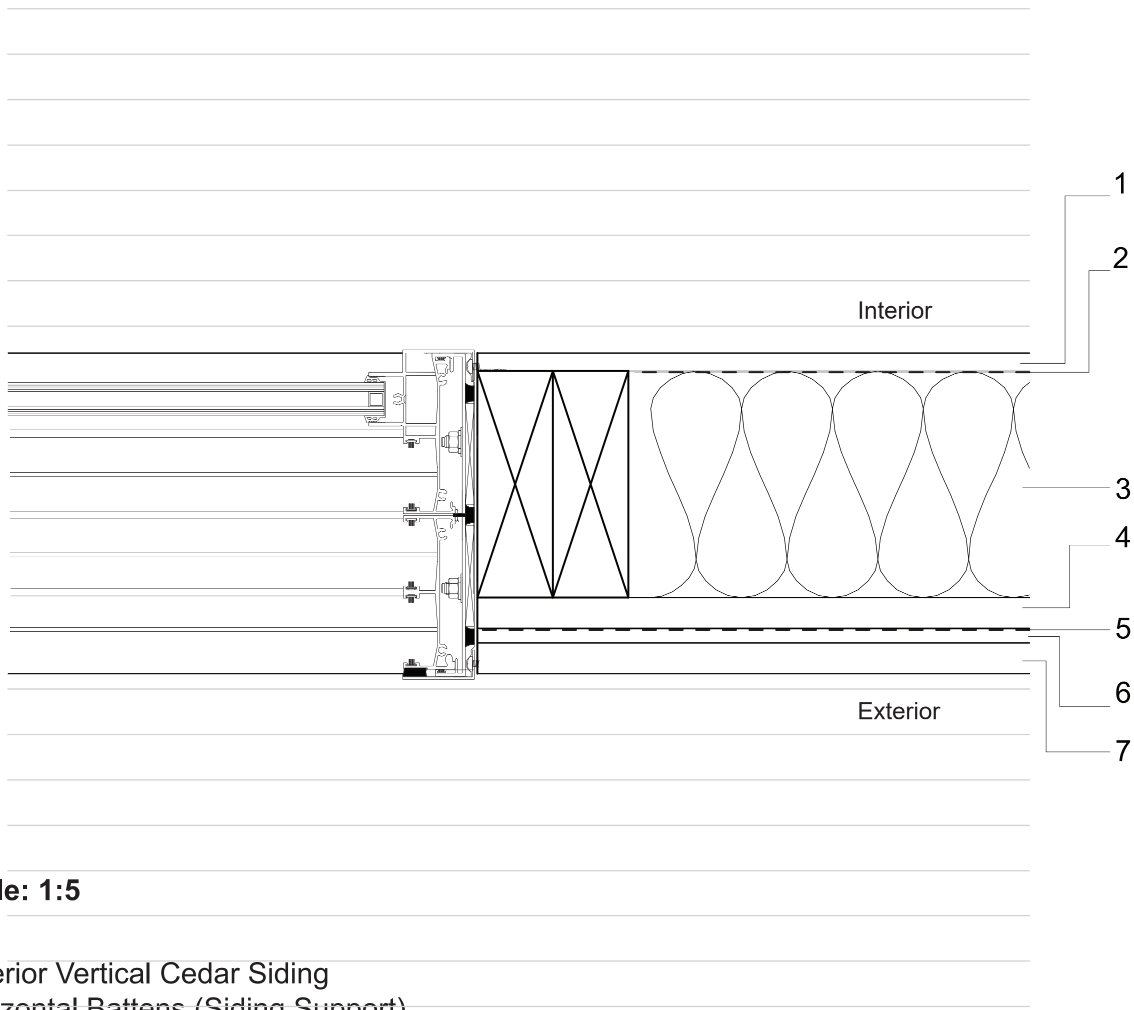


Scale: 1:5

1. Interior Finish
2. Waterproofi membrane
3. Hardwood
4. Insulation
5. Sheathing / Wood Ceiling

The floors in the project are composed of five main layers. On the upper part, the desired finish can vary depending on the space, with the main finish applied in the project being wood. Then, the waterproof membrane and the hardwood, which hold the interior finish in place. Afterward, the insulation, which in this case prevents outdoor humidity from entering the building and ensures airtightness. Furthermore, the lower sheathing or the desired ceiling finish in the lower layer of the floor.

Wall Detail

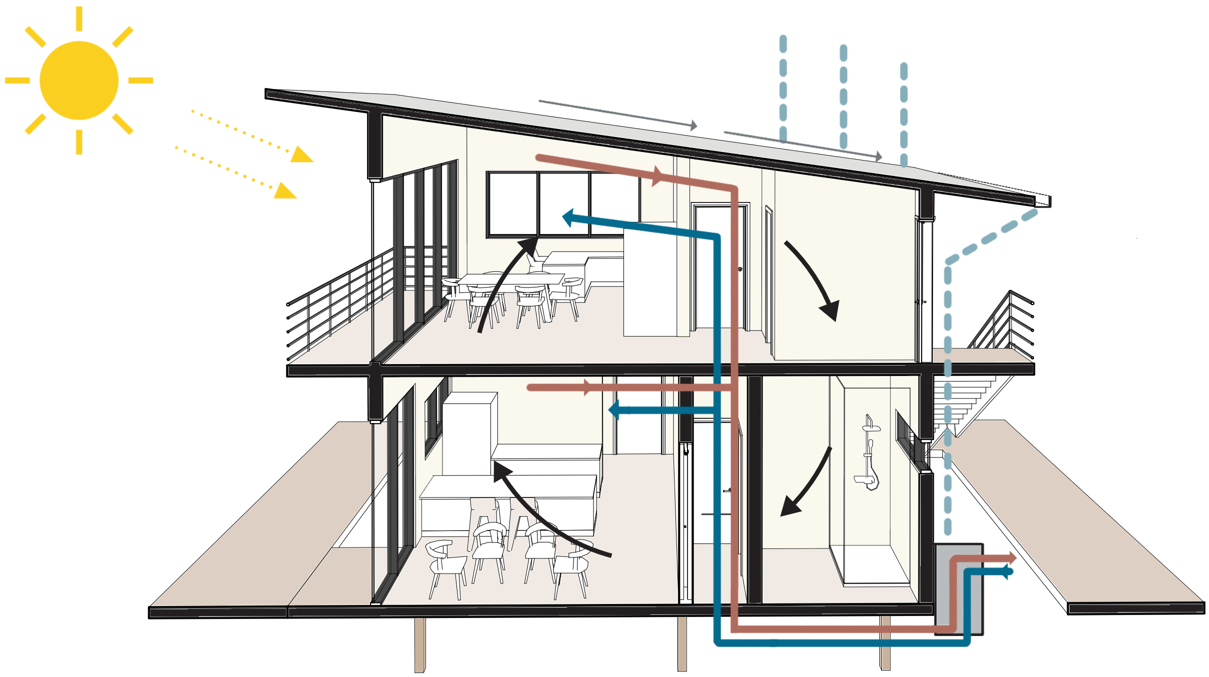


Scale: 1:5

1. Exterior Vertical Cedar Siding
2. Horizontal Battens (Siding Support)
3. Waterproof Membrane
4. Wood Sheathing
5. Insulation & Vertical Sturctural Studs
6. Vapor Barrier
7. Gypsum Drywall Finish

The walls are also composed of seven main layers. Starting from the exterior side, a vertical cedar siding was used in the building. This siding is supported by horizontal battens which provide ventilation within the façade, avoiding humidity problems. Then, the waterproof membrane is placed on the outer side of the wood sheathing. After the sheathing, the insulation is installed to ensure interior thermal comfort and airtightness. Finally, the vapor barrier and the interior gypsum drywall finish.

Airtightness & HRV System



Airtightness in the project is a very important aspect in terms of affordability. This aspect is all about creating a controlled indoor environment by eliminating air leakage. THis means preventing the outside air from infiltrating inside the house and minimizing the escape of air, whether it's heated or cooled. This is important for affordability as it improves energy efficiency by reducing the workload on heating and cooling systems, thereby lowering energy bills. It also enhances indoor comfort, as it helps maintain a consistent indoor temperature and reduces drafts (Energy Star, n.d.).

A Heat Recovery Ventilation (HRV) system is designed to improve indoor air quality while conserving energy. It works by exchanging indoor air with fresh outdoor air. The HRV recovers heat from the outgoing air to pre-warm the incoming air. This process is particularly beneficial in climates like Bowen Island's, as it minimizes the heat loss typically associated with ventilation (Energy Star, n.d.).

By maintaining a balance between airtightness and ventilation, an HRV system ensures that a home remains energy-efficient, comfortable, and healthy. It prevents the buildup of excess humidity and indoor pollutants, making it a crucial component in modern energy-efficient homes.

5. Sustainable Strategies

Sustainable Strategies

Sustainability strategies on Bowen Island should align with the community's eco-conscious values and its unique ecosystem. The emphasis should be on reducing resource usage, using sustainable building materials, and minimizing the ecological footprint (Green Building Council, 2021). Among the concepts of sustainable strategies applied in the project are: building materials used to reduce the carbon footprint, the raised foundation system (palafitic architecture), the potential use of solar panels, and water and snow management with the roof slope.

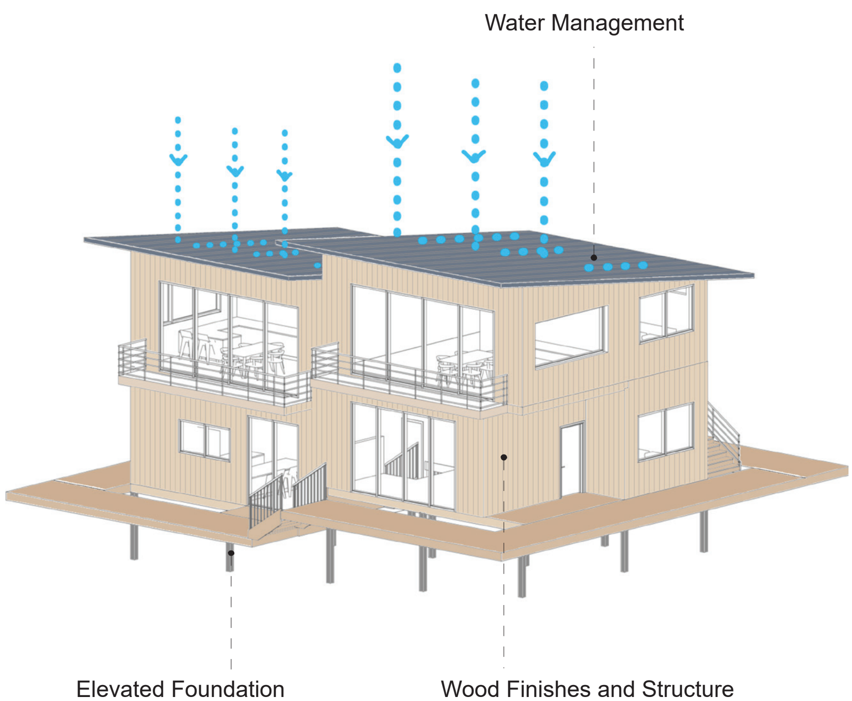
Water Management

Given Bowen Island's substantial rainfall, rainwater harvesting systems can provide non-potable water for irrigation and greywater systems. This approach would relieve pressure on local water supplies, reduce costs, and align with sustainable water management practices (Green Building Council, 2021).

The proposed strategies aim to create housing that aligns with Bowen Island's unique climate, ecological sensitivity, and community values. By incorporating passive solar design, high-performance insulation, renewable energy sources, sustainable materials, water conservation measures, and comprehensive waste management, the project can offer an energy-efficient, sustainable, and community-centered living environment. This approach not only minimizes environmental impact but also serves as a model for future sustainable development on Bowen Island and similar settings (Green Building Council, 2021).

Raised foundation

By separating the house from the terrain multiple benefits come to hand not only in sustainable terms but also in energy efficiency as it provides the house with extra insulation. In terms of sustainability, by elevating the house from the terrain less soil is disturbed during construction, which helps preserve



Solar Panles

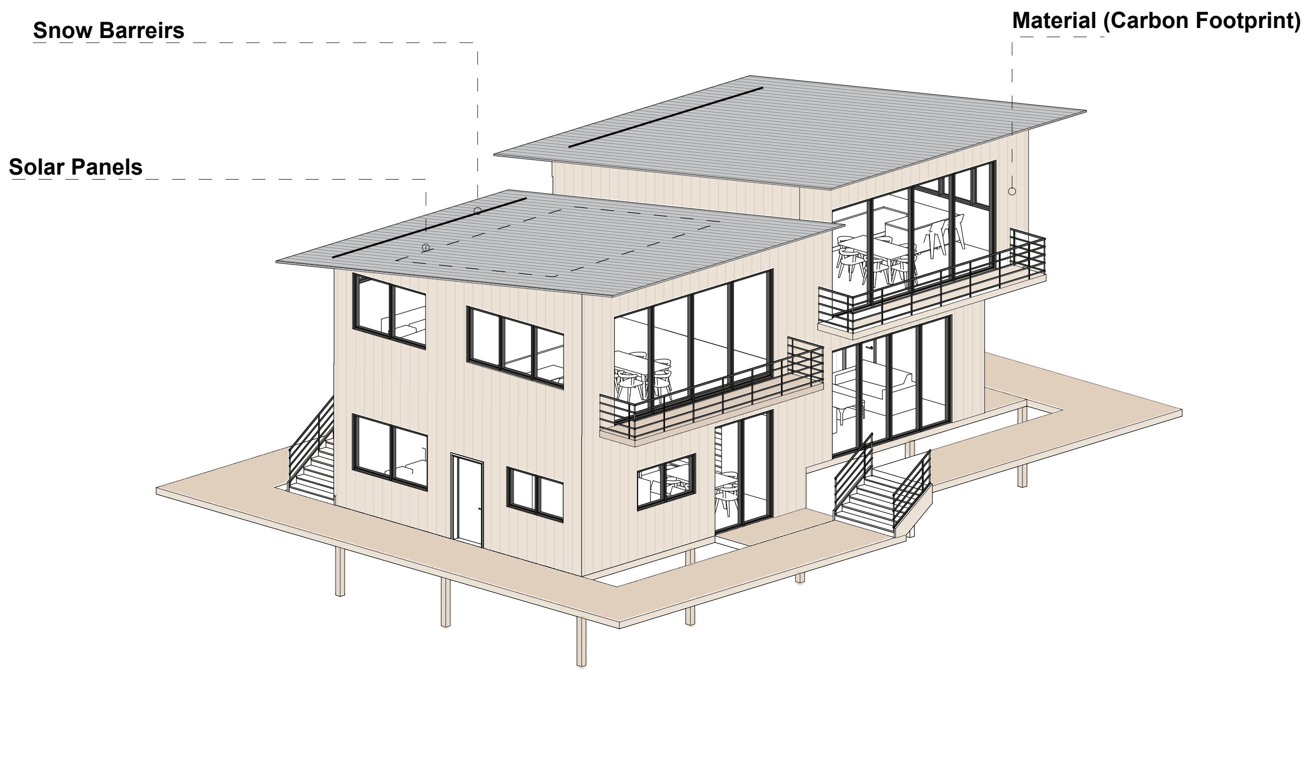
The implementation of solar panels in the project is an important strategy as it represents a clean energy source. Additionally, since one of the main concepts of the proposal is affordability, this strategy directly impacts the energy consumption costs of the house by reducing them significantly.

Snow Barriers

Snow barriers, or snow guards, are an important component in areas where there is heavy snowfall. These devices are designed to prevent the sudden release of snow and ice from the roof, which can pose a hazard to property and individuals below. According to RoofCrafters, proper installation of snow guards is crucial to ensure their effectiveness in protecting the roof and its surroundings (RoofCrafters, n.d.).

Building Materials

Bowen Island has access to locally-sourced timber, which can be a sustainable alternative for its envelope, framing and finishes. Using timber from the local region minimizes transportation emissions and supports local economies. Additionally, wood has a lower embodied carbon footprint than concrete or steel, making it a sustainable choice for the structure and interiors .



Conclusions

Taking into account the multiple factors and conclusions analyzed in the first chapters, this housing proposal addresses the general situation on Bowen Island. First, regarding the territorial analysis, the project is located and configured to respond to the topography of the lot, the orientation based on exposure to the territory, and the environmental requirements. The housing placement within the lot takes into consideration the buffers based on both the natural environment and the island's development regulations. Additionally, knowing that the lot has a height change of nearly 40 meters, it was important to place the volumes in such a way that they wouldn't be affected by this. This was accomplished by placing the unit in the lower slope area with a 15% slope. The use of palafitic architecture was also employed to reduce the natural impact of these housing units, as one of the island's major focuses is to maintain its natural environment. Furthermore, the volumes also respond to a location factor by having a major sun exposure towards the south, achieved by distributing the main indoor activities towards the south and maintaining activities like circulation towards the north.

Additionally, the housing units respond to a population analysis which showed a necessity in the current housing market supply on Bowen Island. It was understood that the market is currently primarily based on family households. This makes it expensive for population groups such as empty nesters who want to downsize, or young adults and workers of the island, to live there. By providing housing units to these population groups, the local economy will be positively affected by offering a workforce that lives on the island and diversifying the population. This may lead to the generation of various different activities in the future.

04

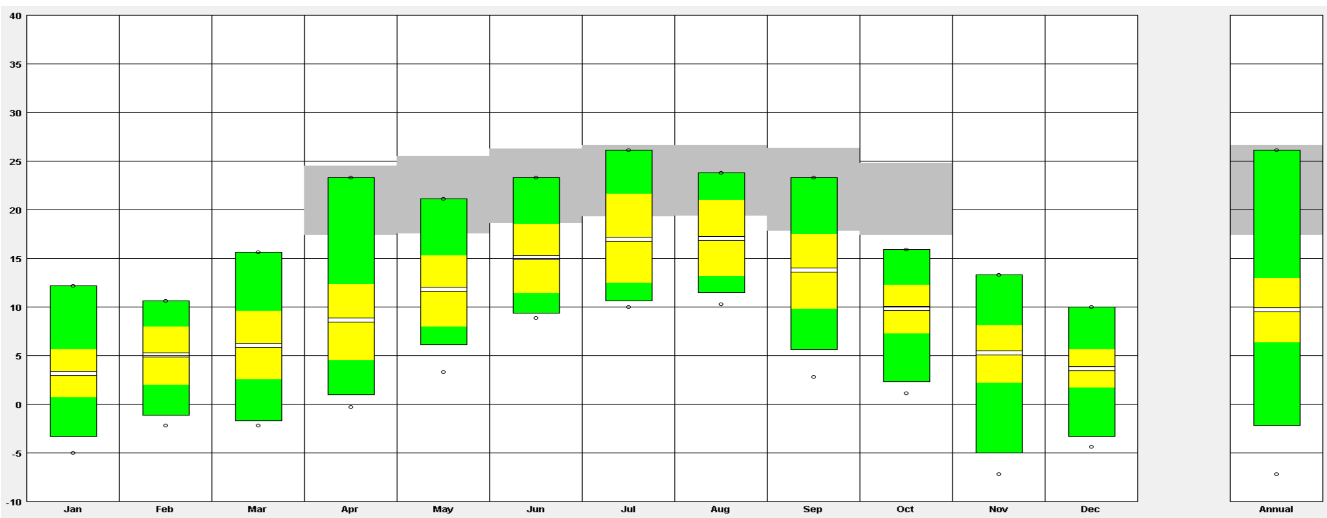
Building Performance

1 Energy performance

1.1 Climatic considerations for Energy-Efficient Design

Understanding the local climate is the very basis for developing energy-efficient building design, thus responding effectively to environmental conditions. On Bowen Island, this peculiar combination of mild but humid winters, important rainfall, and moderate solar exposition provides particular challenges and opportunities regarding the optimization of building performance. These climatic variables directly affect the demand for heating and cooling, moisture management, and in general the overall energy consumption. The proposed multifamily housing would better meet the specific weather patterns of Bowen Island through design strategies that include high-performance insulation, passive solar gain from south-facing windows, and advanced ventilation systems. This approach supports the sustainability and affordability goals through a climate-responsive design that best fits Bowen Island's.

Temperature range

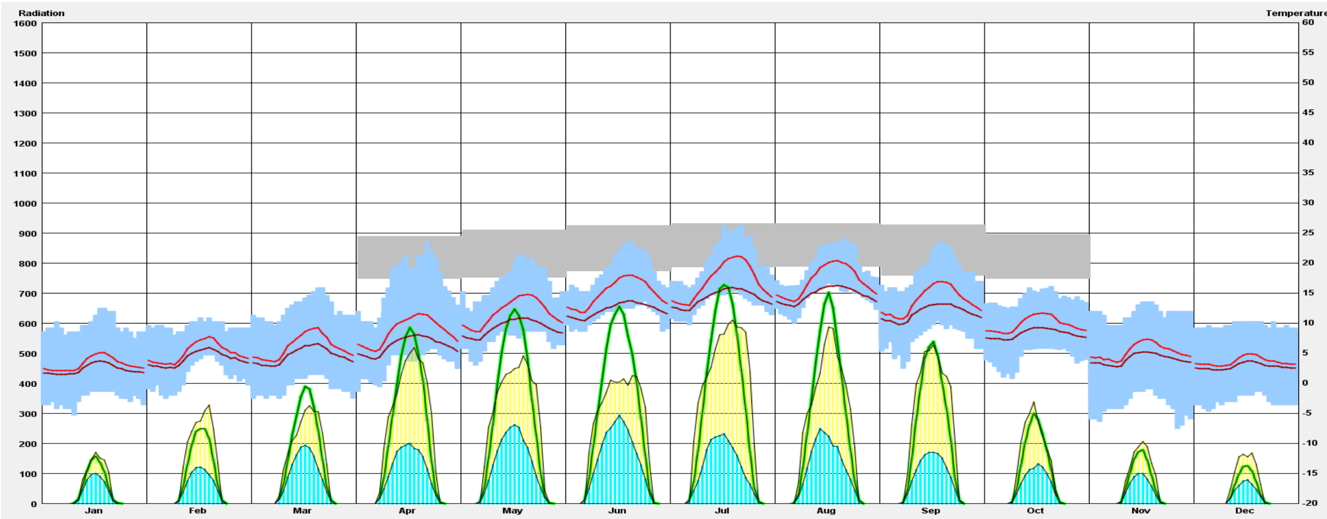


Graph 1: Temperature range - Generated by Climate Consultant software

The temperature range graph shows an extremely dynamic thermal variation ranging from -5°C to 25°C, representing a total thermal amplitude of 30°C. This significant fluctuation implies critical energy performance challenges for the architectural envelope. The data suggest that during winter months, temperatures can go down to -5°C, while in summer they can reach peaks of 25°C (Climate Consultant, 2024).

This extreme variability justifies the implementation of advanced thermal insulation strategies. Preliminary thermodynamic calculations indicate that implementing these strategies on the walls, roof, windows and floor, a reduction of the thermal transmittance coefficient (U) from 2.5 W/m²K to approximately 1.0-1.2 W/m²K could be achieved, representing a 55-60% improvement in thermal insulation (ASHRAE, 2019). Also, the elevation on pilings adds an additional layer of insulation, with an estimated additional 15-20% reduction in heat loss through contact with the ground.

Monthly diurnal averages

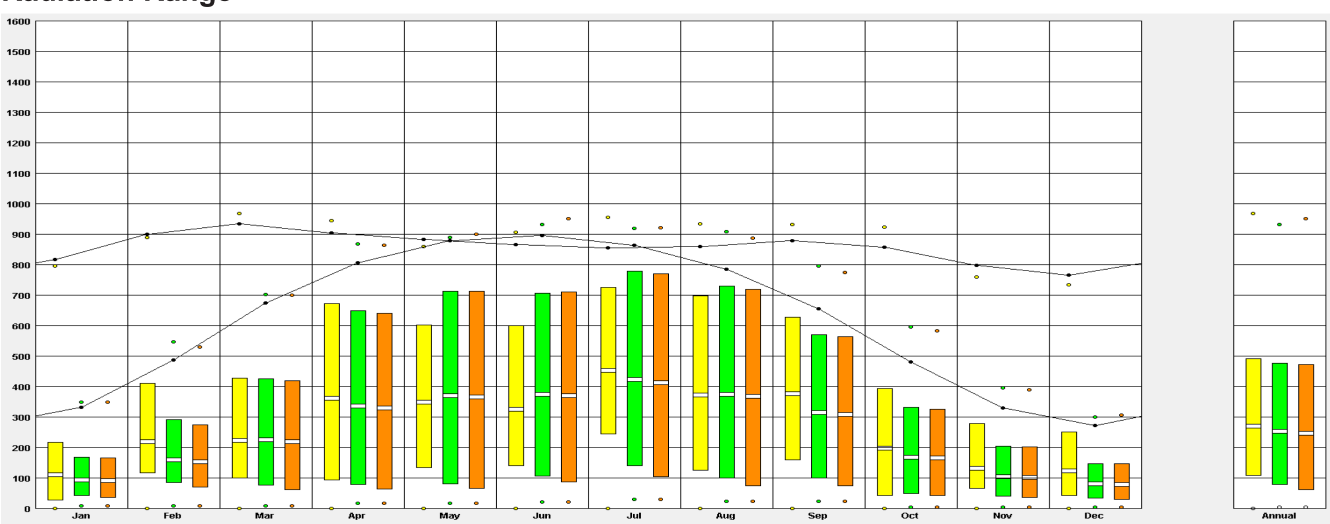


Graph 2: Monthly diurnal averages - Generated by Climate Consultant software

The monthly diurnal average graph presents complex thermal oscillations with a day-to-day variation that may reach differences of up to 12-15°C between the minimum night-time temperature and the maximum daytime temperature. During winter, these variations are more compressed, whereas in summer they are more extended (Climate Consultant, 2024).

A Heat Recovery Ventilation system will be highly needed for the treatment of such fluctuations. Calculation from thermodynamic calculations shows that the amount of recovered heat from extraction air can go from 75 to 85% through a well-designed HRV system, indicating a considerable saving. The south orientation of windows will provide maximum passive solar gain with a potential calculated reduction of heating demand around 25-35%, during coldest months. A selection of a favorable glass will provide the best possible radiation control, with an estimated solar factor within the range of 0.3 to 0.4 in order to optimize natural lighting entry while keeping the increase in unwanted thermal gain at the lowest level (ASHRAE, 2019; Building Science Corporation, n.d.).

Radiation Range



Graph 3: Radiation range - Generated by Climate Consultant software

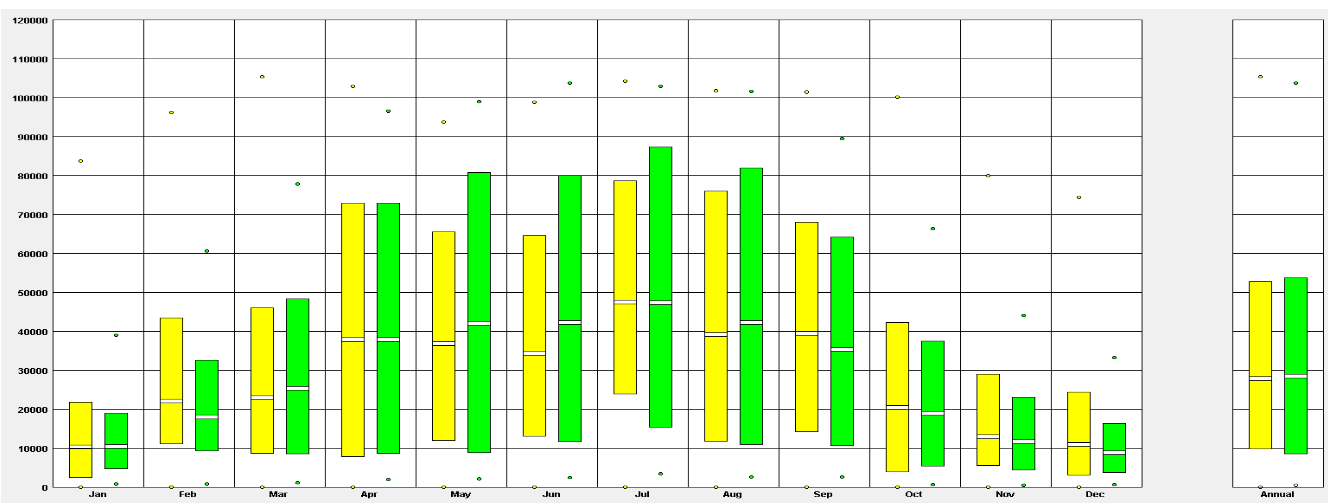
The radiation range graph shows the monthly and daily shifts of solar radiation throughout the year, measured in kWh/m². During the summer months (May to August), solar radiation peaks, arrive to values of approximately 1,200-1,400 kWh/m² per month, indicating significant sunlight availability. During the cold months, which last from November to February, solar radiation also drops and those values range from 200-400 kWh/m² per month. The transitional months such as March, April, September, and October are of moderate radiation which varies from 500-900 kWh/m² per month. These range bars also represent part of the variability of each month but in the case of winter months, there is quite a lot of variability whereas summer months are stable regarding solar radiation. Annual view of the graph exhibits well the solar energy distribution over a long period of time, providing clear indication on summer season being the most productive, while winter months being the least productive ones (Climate Consultant, 2024).

As the location is surrounded by large trees that provide natural shade, additional shading devices are not necessary as the environment regulates excess solar gain. During the summer months, where solar radiation peaks (1,200-1,400 kWh/m²), the natural surrounding trees will help mitigate overheating, allowing efforts to focus on controlling available radiation for natural lighting and, potentially, for power generation through solar panels, which could reduce energy demand by 20-30% (Passive House Institute US, n.d.).

During the winter months, when solar radiation decrease, passive solar heating strategies, such as windows facing the south with high solar gain coefficients, will be needed. These strategies could reduce heating demands by 25-35%, by catching available sunlight to balance heating energy needs (Passive House Institute US, n.d.).

In the spring and fall months, where radiation levels are moderate, daylighting strategies, such as the position of the windows, can minimize the need for artificial lighting, reducing energy demand by approximately 10-15%. In addition, to help with daily swings in radiation, the selection of materials that can store and release heat, are important for maintaining comfortable interior temperatures. These strategies provides efficient energy performance of the building, adapting to the environmental conditions of the site and taking advantage of the natural shade provided by the surrounding trees (Passive House Institute US, n.d.).

Illumination range



Graph 4: Illumination range - Generated by Climate Consultant software

The illumination range chart shows the monthly and daily variation of daylight availability in lux or lumens/m² during the year. On spring and summer months (April to August), the greatest amount of daylight is recorded, reaching peak values of approximately 110,000–120,000 lumens/m², indicating a high availability of daylight. On the other hand, the winter months (November to February) present significantly lower levels, ranging from 10,000–40,000 lumens/m², reflecting conditions of lower brightness and limited daylight. In the transition months (March and September), levels are moderate, between 40,000 and 70,000 lumens/m², offering a balance between light availability and the need for artificial lighting (Climate Consultant, 2024).

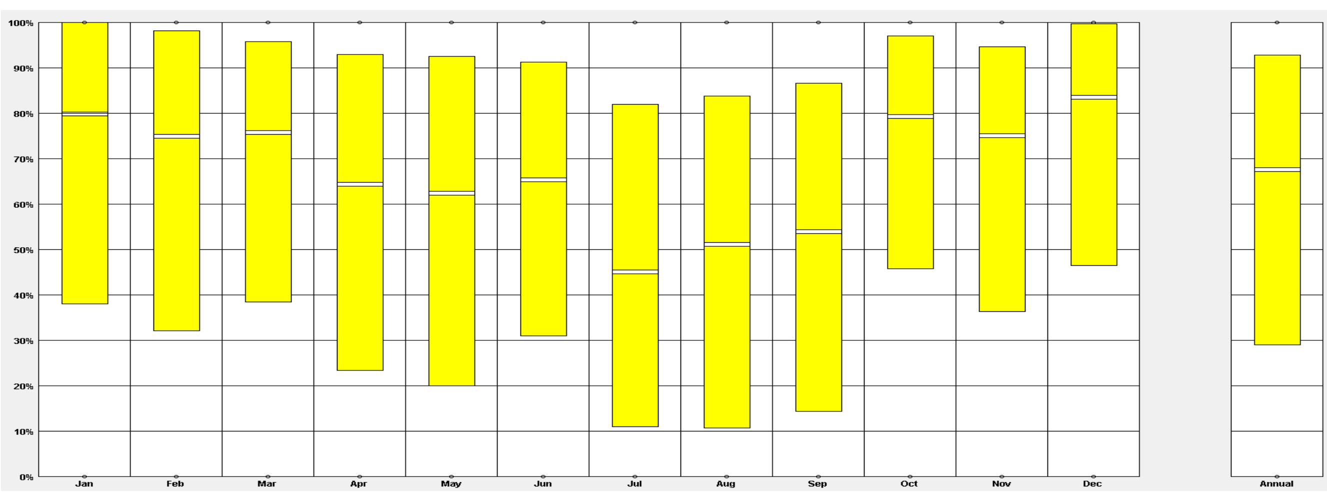
As the graph shows, daily swings are most noticeable during the winter months, with a lot of dark days and days that are barely brighter. In summer, lighting is more regular since the daylight hours are longer and the atmospheric conditions do not change a lot. On an annual basis, the data show a strong contrast between the seasons, with pronounced maximum value in summer and notable minimum value in winter (Climate Consultant, 2024).

Based on the chart information, specific design strategies can be applied to increase daylighting efficiency and minimize energy consumption. During the spring and summer months (April to August), where daylight levels reach up to 120,000 lumens/m², it will be possible to rely almost exclusively on daylight indoors by using appropriately sized and positioned windows, especially on the more south- and west-facing facades. This can reduce artificial lighting demand by an average of 20–30% (Passive House Institute US, n.d.).

In the winter months (November to February), when lighting levels drop to 10,000–40,000 lumens/m², natural lighting will need to be supplemented with efficient artificial lighting, such as energy-efficient LED systems, while optimizing light input through high-transmission glazing. This could reduce the reliance on artificial lighting by 10–15% during the clearest days (Passive House Institute US, n.d.).

In the transition months (March and September), where light levels are moderate (40,000–70,000 lumens/m²), strategically located windows will take advantage of available natural light and minimize the hours of use of artificial lighting systems. Finally, reflective interior surfaces and light colors can be installed, in order to grow light distribution in all seasons, improving visual comfort and reducing annual energy demand for lighting. These strategies, adapted to the annual lighting range, guarantee an efficient and sustainable design that promote the use of natural lighting in the project (Passive House Institute US, n.d.).

Sky cover range



Graph 5: Sky cover range - Generated by Climate Consultant software

The sky cover graph illustrates monthly and daily variation in the percentage of sky covered by clouds throughout the year. The values represent the proportion of the sky covered by clouds, changing between 40% and 100% depending on the month and particular weather conditions. Cloud cover is maintained at a constant level of 80% to 100% during the winter season due to high cloudiness and, as a result, the images are mostly cloudy. This leads to poor direct solar exposure, which consequently impacts efficacy of approaches including passive solar gain and solar energy generation from solar panels. The high degree of cloud cover highlights the necessity of focusing on the collection of diffuse light so as to satisfy effectively the lighting needs in inside environments (Climate Consultant, 2024; Passive House Institute US, n.d.).

During summer, cloud cover is low, ranging from 40% to 80%, and as a result the sky is clearer with the sun's rays more open and easier to access. Nevertheless, substantial diurnal variation is found, implying that cloudy days can still happen even in summer. This variability shows the need for flexible solutions to achieve proper use of the natural light during the seasonThe transitional months (March, April, September, and October) show moderate sky coverage, ranging from 60% to 90%. Months describe weather conditions that swing between sunny and overcast days. Annually, there is a clear seasonal increase in daytime sky transparency in summer and daytime sky cloudiness in winter, although there is intermonthly variation (Climate Consultant, 2024; Building Science Corporation, n.d.).

When sky cover is 100% in the winter, south-facing windows should be given priority. These windows provide full capture of diffuse with light being particularly suitable given the restricted access to direct daylight at this time. In addition, the use of high visible light transmission glass is recommended. Transmittance of light via this type of glass is improved on overcast days with effective reduction in artificial lighting added, with reduction in need of 10-15% (Passive House Institute US, n.d.; Building Science Corporation, n.d.).

During the summer months when there is alteration in the sky coverage between from 40% and 80%, it is recommended that the design strategies focus on exploitation of the available solar energy. This is possible by learning to strategically place windows to take advantage of maximum sunlight. Moreover, the use of reflective materials in interior areas can contribute to the uniform distribution of natural light over the room. These actions can lead to a substantial decrease in artificial lighting needs hence a cut in reliance by approximately 20-30% (ASHRAE, 2019; Building Science Corporation, n.d.).

During the transitional months, with moderate sky cover ranging from 60% to 90%, strategies can integrate natural lighting with dynamic control systems, such as light sensors that adjust artificial lighting based on daily conditions. This approach guarantees that artificial lighting is employed only when needed, which improves energy efficiency. By implementing these strategies, the architectural design both increase natural light availability according to seasonal patterns and reduce the energy impact of artificial lighting, adapting to the specific climatic conditions of the site (ASHRAE, 2019; Passive House Institute US, n.d.).

During winter, when the sky cover is between 80 to 100% , and solar radiation is low, the Heat Recovery Ventilation system becomes an important factor in indoor air quality and comfort. The HRV system can recover up to 85% of the heat from extracted air, reducing energy losses associated with ventilation and allowing the circulation of fresh air even in cases where the temperature is low and cloudy. This complementing to the other strategies mentioned, allowa combined energy efficiency and thermal comfort even for the cloudiest period of the year (Passive House Institute US, n.d.).

1.2 Efficiency indicators

1. Heating Degree Days (HDD)

Heating Degree Days (HDD) is the accumulated difference between the average daily outdoor temperature and the reference temperature commonly set at 18°C. Usually, HDD gives a general idea about the estimated heating demand with respect to prevailing weather conditions. In those cases when the average daily temperature of the outdoors is lower than 18°C, the differences are summed to calculate the HDD. This indicator is important for guidance to heating requirements and for proposing solutions for energy efficiency in building design, under consideration of the climate conditions (ODYSSEE-MURE, 2020, p. 7).

On Bowen Island the winter is moderate, where the temperature averages are between 3° and 6°C, totalling about 3,800 HDDs annually (Time and Date, 2024; Weatherbase, 2024). This moderate heating demand suggests the implementation of design strategies that take advantage of passive heating and reduce heat loss.

2. ODEX (Energy Efficiency Index)

Energy Efficiency Index or ODEX quantifies technical efficiency in improvements in energy efficiency and takes into account structural changes in the economy or change of consumption habits that may also have an impact on energy demand. The indicator quantifies changes in unit energy consumption at subsector/end-use level as a weighted average, where the relative weight of each subsector in total consumption is based on share of each sub-sector consumption. The ODEX values may be calculated for separate sectors such as industry, transport, or households, or for the overall economy. A decrease in ODEX shows that there is a positive technical improvement in energy efficiency (ODYSSEE-MURE, 2020, pp. 12-14). For the multifamily project in Bowen Island, reducing the average energy consumption from by implementing energy-efficient building materials and systems would result in a percentage improvement in ODEX.

3. Energy Consumption per Unit of Area (kWh/m²)

This indicator is computed as the sum of the energy consumption in kWh/m² divided by the building area. The primary purpose is to establish the merit of policy to save energy and to compare the efficiency of energy consumption among buildings (ODYSSEE-MURE, 2020, p. 16).

On Bowen Island, energy consumption for heating in standard buildings is approximately 150 kWh/m² annually (Time and Date, 2024). By integrating design strategies related to building envelope and ventilation systems the target consumption can be reduced considerably, ensuring thermal comfort and sustainability, with the consideration of local climatic conditions.

4. Degree-Day Adjusted Energy Consumption

Degree-day adjusted energy consumption represents the compensation of the energy consumption with seasonal climatic changes in order to have a consistent evaluation of the energy performance of the building in diverse environments. This adjustment removes the impact of any extreme or mild winters, ensuring that the evaluation of energy efficiency measures is neutral for the climate site (ODYSSEE-MURE, 2020, p. 20).

With around 3,800 HDD per year (Time and Date, 2024; Weatherbase, 2024), applying strategies such as high-performance insulation, south-facing glazing, and airtight construction can reduce heating consumption by 30%. This refers to a reduction in energy demand for heating from 6,000 kWh per year to 4,200 kWh per unit.

5. Degree-Day Adjusted Energy Consumption
This indicator has the effect of converting energy savings to avoided CO2 emissions, and thus can give an idea of the environmental contribution of energy saving interventions. The avoided emissions are determined by multiplying the energy saved (kWh) times an emissions factor (kg CO2/kWh). It is an important indicator of the role of energy efficiency towards climate change mitigation targets (ODYSSEE-MURE, 2020, p. 22).

Savings of 1 kilowatt-hour are about to avoid 0.2 kg of CO2 emissions from being produced. If an estimated annual energy savings of 3,000kWh/unit is available for the entire complex 5.4 tons of CO2 will be avoided (ODYSSEE-MURE, 2020).

1.3 Building envelope

The thermal envelope of a building is one of the key factors that directly impacts on the energy efficiency, thermal comfort, and environmental sustainability. On Bowen Island, with mild winters and average temperatures of 3°C to 6°C and high annual humidity (around 80%), the selection of materials and design strategies must manage specific challenges to ensure an ideal performance (Time and Date, 2024; Weatherbase, 2024). This analysis search both reducing heat losses and improve energy efficiency, and to reduce the environmental impact and provide a comfortable and indoor quality environment.

To achieve this purpose, we used the Cove.Tool software to select envelope materials, comparing different options based on parameters such as U-value (heat transfer coefficient) and R-value (thermal resistance). Factors such as cost, energy consumption and thermal comfort were also evaluated (Cove. Tool, n.d.). This detailed approach helped to identify solutions that combine optimal technical and economic performance, with a special focus on environmental sustainability. Additionally, local materials were chosen for construction, which not only reduced transportation costs but also helps with the carbon footprint, in line with sustainable design principles (Jones & Hammond, 2020).

Window selection and dimensions were an important aspect of the thermal envelope analysis. They were evaluated not only for their thermal properties, but also for their ability to integrate with the other design strategies. These strategies include south-facing orientation, designed to increase the passive solar radiation gain (ASHRAE, 2019), and elevating the homes on pilings, which provides additional insulation by limiting heat transfer from the ground (Passive House Institute, 2018). These strategies, combined with the envelope materials, were analyzed to guarantee an integrated result that optimizes both energy performance and indoor quality.

This chapter also shows an integral analysis of the project’s thermal envelope, highlighting the results obtained using Cove.Tool software and the factors considered during the selection process. These include local climate conditions, environmental impact, associated costs, and specific project needs. It also explores how the integration of these strategies enables an efficient, sustainable design adapted to the unique context of Bowen Island. The ultimate goal is to achieve a balance between reduced energy consumption, thermal comfort and long-term sustainability.

Wall envelope

Layer	Material	Thickness (mm)	Thermal Conductivity (W/m·K)	R-Value (m²·K/W)	U-Value (W/m²·K)	Provider	Cost per m² (CAD)	Total Cost (CAD)
External Layer (Cladding)	Treated Cedar Wood	20	0.14	0.1429	7,0000	Bowen Building Centre	65.0	13,734.50
Waterproof Layer	Waterproof Membrane	0.2	1000	0.0002	5000,00	Pacific Coast Building Products	4.5	950.85
Middle Layer (Thermal Insulation)	Rigid Polyurethane Foam	150	0.02	7,5000	0.1333	Green Building Store	42.5	8,979.25
Internal Layer (Humidity & Finish)	Gypsum Board	12	0.25	0.0480	20,8333	Home Lumber & Building Supply	20.0	4,226.00
Internal Layer (Additional Insulation)	Wood Fiber Insulation	25	0.04	0.6250	1,6000	Insulation Warehouse	32.5	6,866.25
Vapor Barrier Layer	Vapor Barrier Membrane	0.2	1000	0.0002	5000,00	Pacific Coast Building Products	4.5	950.85

Chart 1: Wall envelope materials properties and costs

The selection of materials for the building envelope was focused in optimizing the energy performance of the building, while thermal comfort. Each material is contributing toward the project's objectives on sustainability and efficiency. Treated cedar wood cladding on the facade, provides durability and moderate thermal resistance, it is also sourced locally to minimize embodied carbon (Passive House Institute, 2018). After this layer, the watertight membrane will prevent infiltrations of moisture and protect not only the structure but also maintain the efficiency of thermal insulation (ASHRAE, 2019).

The primary insulation selected is rigid polyurethane foam, with an extremely high R-value of 7.500 m²·K/W to reduce heat transfer by a high factor, therefore, minimizing energy demand for heating and cooling (ASHRAE, 2019). To complement this, insulation made from wood fibers will provide additional thermal resistance by using renewable materials and increasing the total performance of the envelope (European Insulation Manufacturers Association, 2020).

Inside, gypsum board provides stable inside temperatures and adds extra fire resistance and structural strength (Building Materials Data Handbook, 2020). The vapor barrier membrane allows for proper moisture management and keeps the condensation out of the building that would destroy the integrity of the insulation layers (ASHRAE, 2019). These materials together allow the creation of a well-balanced building envelope with high-performance characteristics, meeting the Passive House specifications. This envelope reduces thermal losses and improves indoor air quality to low energy use within the building (Passive House Institute, 2018).

Detailed Calculations by Material

1. Treated Cedar Wood
Thickness: 20 mm = 0.02 m
Thermal Conductivity (λ): 0.14 W/m·K *(Source: Passive House Institute, 2018).*
Thermal Resistance (R): R = d / λ = 0.02 / 0.14 = 0.143 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.143 = 7.000 W/m²·K

2. Waterproof Membrane
Thickness: 0.2 mm = 0.0002 m
Thermal Conductivity (λ): 1000 W/m·K *(Source: Standard Manufacturer Data).*
Thermal Resistance (R): R = d / λ = 0.0002 / 1000 = 0.0002 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.0002 = 5000.000 W/m²·K

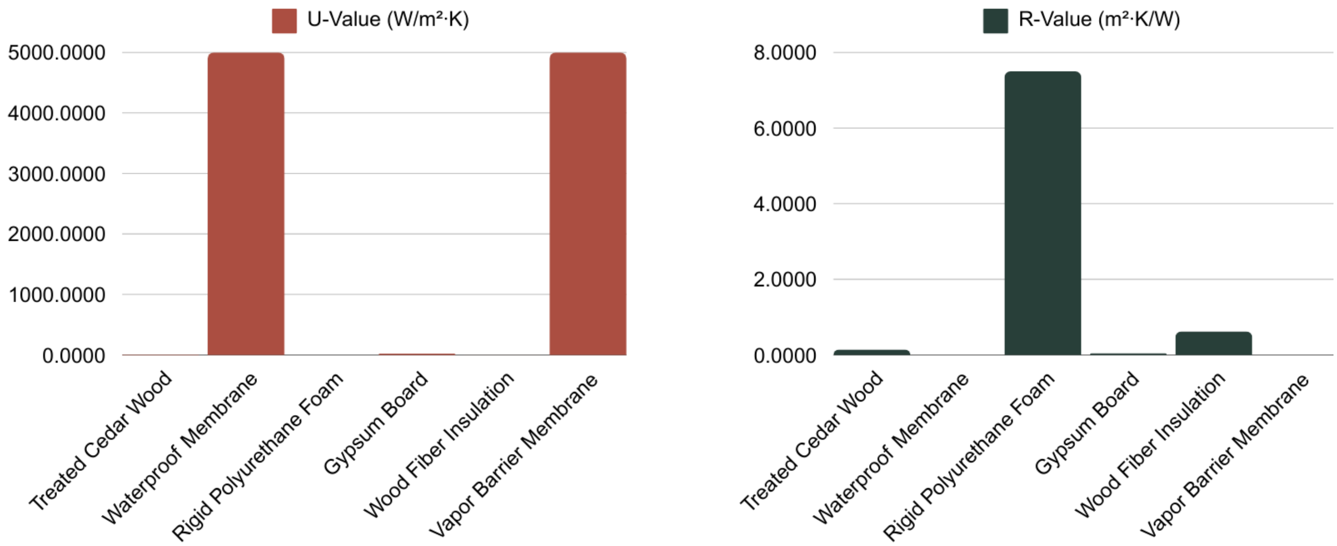
3. Rigid Polyurethane Foam
Thickness: 150 mm = 0.15 m
Thermal Conductivity (λ): 0.02 W/m·K *(Source: ASHRAE Handbook, 2019).*
Thermal Resistance (R): R = d / λ = 0.15 / 0.02 = 7.500 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 7.500 = 0.133 W/m²·K

4. Gypsum Board
Thickness: 12 mm = 0.012 m
Thermal Conductivity (λ): 0.25 W/m·K *(Source: Building Materials Data Handbook, 2020).*
Thermal Resistance (R): R = d / λ = 0.012 / 0.25 = 0.048 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.048 = 20.833 W/m²·K

5. Wood Fiber Insulation
Thickness: 25 mm = 0.025 m
Thermal Conductivity (λ): 0.04 W/m·K *(Source: European Insulation Manufacturers Association, 2020)*.
Thermal Resistance (R): R = d / λ = 0.025 / 0.04 = 0.625 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.625 = 1.600 W/m²·K

6. Vapor Barrier Membrane
Thickness: 0.2 mm = 0.0002 m
Thermal Conductivity (λ): 1000 W/m·K *(Source: Standard Manufacturer Data)*.
Thermal Resistance (R): R = d / λ = 0.0002 / 1000 = 0.0002 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.0002 = 5000.000 W/m²·K

Total Wall U-Value Calculation
U total = 1 / ΣR U_total = 1 / (0.143 + 0.0002 + 7.500 + 0.048 + 0.625 + 0.0002)
= 1 / 8.3164 = 0.1202 W/m²·K



Graph 1: Wall envelope U value and R value

Wall envelope design for the Bowen Island project does achieve and exceed building performance and energy efficiency requirements, achieving exceptional thermal performance and sustainability. Using an overall R-Value of 8.316 m2·K/W, the wall system offers insulation, that sets a reduction in the heat transfer and thus energy wasting during the heating and the cooling seasons. This performance is in agreement or better than Passive House requirements, U-value 0.15 W/m 2·K, as obtained from the calculated U-value of 0.120 W/m 2·K as reported by the Passive House Institute (2018). These findings validate that the wall space envelope offers strong barrier against convective heat loss and acts directly minimising the building's energy needs.

The implementation of high-performance materials was the main factor leading to these results. The treated cedar wood fibre cladding is moderately heat resistant, and also environmental targets are addressed by reducing embodied carbon by using native wood products (Passive House Institute, 2018). Rigid polyurethane foam insulation is the main thermal barrier and delivers an unprecedentedly high to R-Value, and wood fiber insulation is added as a further resistance in forms of renewable, sustainable materials (ASHRAE, 2019). Auxiliary materials like gypsum board, vapor barriers and waterproof membranes provide durability, moisture resistance and stability which maintain the integrity of the envelope over time (Building Materials Data Handbook, 2020).

Through addressing important aspects such as thermal resistance, moisture control, and sustainability, the design of the wall envelope is being directly instrumental in achieving the project's objective of lowering total energy use by between 50% and 70% (Passive House Institute, 2018). These findings corroborate the methodology used for material selection and envelope design, promoting the achievement of the energy efficiency standards and serving as a base for an environmentally friendly building. This performance proves that not only the building envelope is effective, but it works to the new sustainability practice, it is a sustainable solution for energy-efficient housing houses.

Comparison to standard houses

Standard wall envelope

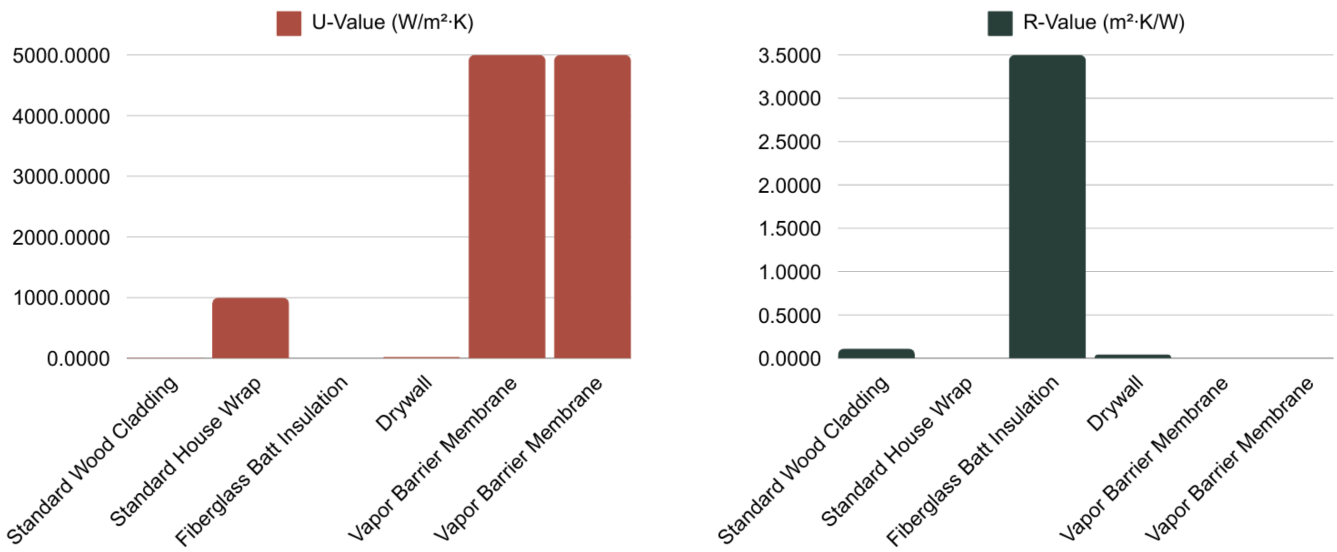
Material	R-Value (m²·K/W)	U-Value (W/m²·K)	Description
Standard Wood Cladding	0.111	9.009	Typical untreated wood siding for exterior cladding.
Standard House Wrap	0.001	1.000.000	Basic moisture-resistant barrier.
Fiberglass Batt Insulation	3.500	0.286	Standard insulation used in stud walls.
Drywall	0.045	22.222	Standard interior gypsum board.
Vapor Barrier Membrane	0.0002	5.000.000	Basic polyethylene vapor barrier.

Chart 2: Standard wall envelope materials properties

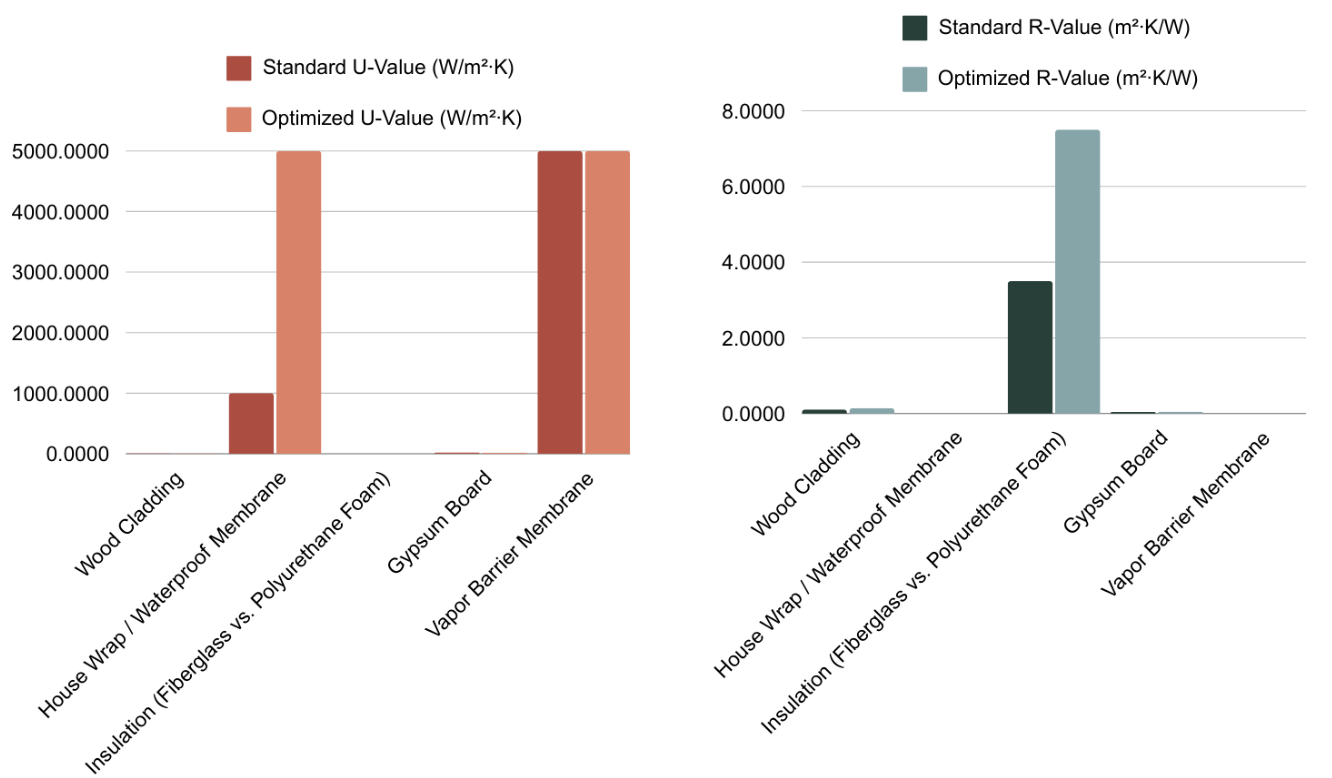
Standard construction materials commonly used in residential buildings on Bowen Island, such as untreated wood cladding, fiberglass batt insulation, basic house wraps, and gypsum board, fail to deliver the level of energy efficiency required for modern, sustainable construction. However, these, although cheap and commercially available, do not have the thermal resistance and moisture management features to comply to requirements on energy performance. Untreated wood cladding has a very low R-Value (0.111 m²/K·W) and a very high U-Value (9.009 W/m²/K), which not provides adequate insulation and allows a big heat transfer from the external walls (ASHRAE, 2019). Similarly, a fiberglass batt insulation, with an R-value of 3.500 m²·K/W it is a lot less energy-saving material than the typical modern insulation materials, leading to an increase in heating and cooling energy rate consumption (Passive House Institute, 2018).

Basic house wraps and vapor barriers used in standard construction also contribute minimally to thermal performance. Having tiny R-Values and very high U-Values (e.g., 1000 W/m2·K), they offer little to no extra insulation and are essentially used for moisture management. Nevertheless, without robust integration with high-performance insulation, these materials lack sufficient ability to stop heat transfer/ energy loss (Building Materials Data Handbook, 2020). Gypsum board, the usual material for interior finishes, provides only a small thermal resistance (R-Value 0.045 m²·K/W) and does not significantly help to improve the energy efficiency of the building (ASHRAE, 2019).

These materials, work for basic construction needs, but do not address the requirements for reducing energy consumption or improving thermal performance to meet energy efficiency indicators. The restricted thermal resistance leads to higher U-values with complications to get the insulation level required for Passive house standards or similar certifications. Traditional building materials make it difficult to meet modern standards of energy efficiency and it often leads to using more energy, which elevates the utility bills and carbon footprint. Towards this goal of creating the Passive Homes of the future, which will have reduced conservational energy usage, more comfort and livability, and lower cost and ecological impact through the adoption of sustainable materials and design strategies. It highlights the need to shift away from traditional building materials and adopt high-performance solutions that are crucial for making construction sustainable and energy-efficient.



Graph 2: Standars wall envelope U value and R value



Graph 3: Comparison of wall envelope U value and R value of standard and optimized materials

Through this graphs, is shown that most of the buildings made from traditional materials cannot meet the demand for energy efficiency in modern times; as such, they consume more energy, increasing utility bills and affecting the environment more when compared to buildings made from new, improved, and energy-efficient materials. This indicates the need for a change from traditional ways of construction to new and advanced ones that are focused on the performance. This, reflects the need of adjusting to sustainable materials and design strategies, in order to create homes that not only lower energy consumption but also offer improved comfort, reduced costs, and a represent a smaller environmental footprint.

Calculations for CO2 Reduction

1. Standard Energy Consumption (Without Improvements):
E standard = 150 kWh/m²/year × 211.3 m² = 31,695 kWh/year
This value (150 kWh/m²/year) is based on typical energy consumption for walls in conventional buildings without insulation improvements, as shown in ASHRAE Handbook (2019).

2. Optimized Energy Consumption (With Current Design):
E optimized = 45 kWh/m²/year × 211.3 m² = 9,508.5 kWh/year
This value (45 kWh/m²/year) was taken from Passive House standards for high-performance walls, using Passive House Institute (2018) as a guideline for the energy performance of optimized envelopes.

3. CO2 Emissions Without Improvements:
CO2 standard = 31,695 kWh/year × 0.2 kg CO2/kWh = 6,339 kg CO2/year
The CO2 emission factor (0.2 kg CO2/kWh) is a standard average emission factor based on the global electricity mix, shown in IPCC Guidelines.

4. CO2 Emissions With Current Design:
CO2 optimized = 9,508.5 kWh/year × 0.2 kg CO2/kWh = 1,901.7 kg CO2/year
The calculation uses the same emission factor (0.2 kg CO2/kWh) and applies it to the energy consumption of the optimized envelope, derived from the Passive House Institute (2018).

5. Total CO2 Reduction:
CO2 reduction = 6,339 kg/year - 1,901.7 kg/year = 4,437.3 kg CO2/year
This reduction is achieved by comparing the emissions from the standard and optimized energy consumption levels, calculated using data from ASHRAE Handbook (2019) and Passive House Institute (2018).

Design of the wall envelope has been confirmed as a critical issue in CO2 reduction by optimizing energy usage in heating and cooling through high performance materials like rigid polyurethane foam and wood fiber insulation that bring to the envelope a U-Value of 0.120 W/m²·K this value is below the standard construction requirements. This heat transfer reduction corresponds to a lower energy requirement with an estimated, annual, savings of 31,695 kWh/year over a traditional wall configuration.

Therefore, the project provides an average CO2 emission decrease of about 4 437 kg per year and per dwelling in the scope. This reduction emphasizes the benefits of utilizing advanced thermal insulation, locally sourced cedar wood, and sustainable building practices to improve energy efficiency and reduce environmental impact. The wall envelope meets energy efficiency goals by saving several thousand kilograms of CO2 annually, while also aiding in climate change mitigation and supporting sustainable construction methods.

Roof envelope

Layer/Material	Thickness (mm)	Thermal Conductivity λ (W/m·K)	R-Value (m²·K/W)	U-Value (W/m²·K)	Provider	Cost per m² (CAD)	Total Cost (CAD)
Galvanized Steel	0.7	50	0.000014	71428.57	SteelCo Supplies	20.00	3,520.00
Wood Structure and Ventilation	20	0.12	0.167	6.00	TimberTech Local	15.00	2,640.00
Waterproof Membrane	18	1000	0.018	55.56	SealPro Membranes	10.00	1,760.00
Sheathing	10	0.15	0.067	15.00	BuildCore Sheathing	12.00	2,112.00
Insulation (Mineral Wool)	150	0.04	3.750	0.27	EcoInsulate	25.00	4,400.00
Vapor Barrier	0.2	1000	0.0002	5000.00	SealPro Membranes	10.00	1,760.00
Wood Sheathing/Internal Finish	10	0.15	0.067	15.00	TimberTech Local	12.00	2,112.00

Chart 3: Roof envelope materials properties and costs

The materials used for the shed's roof is a key factor affecting thermal efficiency and the long-term durability of the project. The galvanized steel coating works very well as a weather barrier, therefore it is robust and requires minimal maintenance, both of which are critical for Bowen Island's (ASHRAE, 2019) coastal climate. Under the steel, wood frame and ventilation system, proper air circulation is established in a way that prevents condensation and ensures the performance of insulation is preserved (Building Materials Data Handbook 2020). The waterproof membrane provides an extra layer to prevent ingress of moisture, maintains the waterproofness of the roof layers and prevents water penetration (Passive House Institute, 2018).

The use of mineral wool insulation, high in thermal resistance, is one of the fundamental features of the roof's energy performance. This layer has an important effect of decreasing heat flow by preventing heat loss in winter and heat gain in summer and thus also reducing energy usage for heating and cooling (ASHRAE, 2019).

The sheathing layers and wood sheathing/internal finishes provide added structural stability and improve thermal performance, enabling the roof to support high loads, including snow load (Passive House Institute, 2018).

On the other hand, the vapor barrier membrane protects the insulation from water intruding, thus providing the roof with a durable performance- long term (Building Materials Data Handbook, 2020). Combined, these materials not only satisfy but also surpass contemporary energy efficiency requirements and that all adds up to a reduction in energy use as well. The roof materials are of particular significance in systematically regulating heat dissipation and moisture conditions, in turn contributing so far to the highest possible thermal performance of the building, to its longevity, and to its satisfactory indoor climate. The adoption of high-performance, eco-friendly materials is consistent with the objectives of the project to reduce the environmental footprint and provide an enduring energy efficiency (Passive House Institute, 2018).

Detailed Calculations by Material

1. Galvanized Steel
Thickness: 0.7 mm = 0.0007 m
Thermal Conductivity (λ): 50 W/m·K *(Source: ASHRAE Handbook, 2019).*
Thermal Resistance (R): R = Thickness / Thermal Conductivity = 0.0007 / 50 = 0.000014 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.000014 = 71428.57 W/m²·K

2. Wood Structure and Ventilation
Thickness: 20 mm = 0.02 m
Thermal Conductivity (λ): 0.12 W/m·K *(Source: Building Materials Data Handbook, 2020).*
Thermal Resistance (R): R = Thickness / Thermal Conductivity = 0.02 / 0.12 = 0.167 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.167 = 6.00 W/m²·K

3. Waterproof Membrane
Thickness: 18 mm = 0.018 m
Thermal Conductivity (λ): 1000 W/m·K *(Source: Passive House Institute, 2018).*
Thermal Resistance (R): R = Thickness / Thermal Conductivity = 0.018 / 1000 = 0.000018 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.000018 = 55.56 W/m²·K

4. Sheathing
Thickness: 10 mm = 0.01 m
Thermal Conductivity (λ): 0.15 W/m·K *(Source: ASHRAE Handbook, 2019).*
Thermal Resistance (R): R = Thickness / Thermal Conductivity = 0.01 / 0.15 = 0.067 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.067 = 15.00 W/m²·K

5. Mineral Wool Insulation
Thickness: 150 mm = 0.15 m
Thermal Conductivity (λ): 0.04 W/m·K *(Source: ASHRAE Handbook, 2019).*
Thermal Resistance (R): R = Thickness / Thermal Conductivity = 0.15 / 0.04 = 3.75 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 3.75 = 0.27 W/m²·K

6. Vapor Barrier
Thickness: 0.2 mm = 0.0002 m
Thermal Conductivity (λ): 1000 W/m·K *(Source: Passive House Institute, 2018).*
Thermal Resistance (R): R = Thickness / Thermal Conductivity = 0.0002 / 1000 = 0.0000002 m²·K/W
Thermal Transmittance (U): U = 1 / R = 1 / 0.0000002 = 5000.00 W/m²·K

Total Roof U-Value Calculation

U total = 1 / ΣR = 1 / (0.000014 + 0.167 + 0.000018 + 0.067 + 3.75 + 0.0000002) = 1 / 3.9840322 = 0.251 W/m²·K

Comparison to standard houses

Standard roof envelope

Material	R-Value (m²·K/W)	U-Value (W/m²·K)	Description
Standard Asphalt Shingles	0.044	22.727	Basic weather-resistant roof covering.
Standard Roofing Felt	0.005	200.000	Standard moisture barrier for roofing.
Fiberglass Batt Insulation	3.500	0.286	Common insulation used in roofs for moderate climates.
Plywood Sheathing	0.067	15.000	Structural support layer under roof materials.
Basic Vapor Barrier Membrane	0.0002	5.000.000	Basic polyethylene vapor barrier.

Chart 4: Standard roof envelope materials properties

The chosen materials for the roof envelope are thermally performant, as they are evidenced by the calculated overall U-Value=0.251 W/m²·K and overall R-Value= 3.984 m²/K·W (ASHRAE, 2019). These values confirm that the roof provides an outstanding level of insulation, therefore also taking into account the heat exchange and the losses of energy through the envelope of the building.

This mineral wool insulation, with a high R-Value of 3.75 m²·K/W, is the main thermal protection element of the roof system. This material is essentially an important factor in the energy saving from the heat loss during winter and the heat gain during summer, thus reducing the need for a mechanical heating and cooling system (Passive House Institute, 2018). The performance of this insulation is in accordance with the low overall U-Value, which reflects high thermal resistance (ASHRAE, 2019).

Supplementary materials, wood structure thermal insulation (R 0.167 $m^2 \cdot K/W$) and ventilation layer thermal insulation (R 0.067 $m^2 \cdot K/W$) and sheathing (R 0.067 $m^2 \cdot K/W$), provide further layers of thermal resistance, and can be summarized by their building material performance (Building Materials Data Handbook, 2020). Vapor barrier and waterproof membrane, although not significantly affecting the thermal resistance, play a critical role in the moisture control. They insulate the insulation layers against condensation and water penetration, retaining their performance over time and, thereby, maintaining the insulating function of the roof (ASHRAE, 2019).

The relatively low total U-Value (0.251 $W/m^2 \cdot K$) reveals that the roof envelope is above common energy performance criteria and leads to reduced energy usage and increased indoor comfort (Passive House Institute, 2018). This degree of thermal efficiency allows the roof to comply with the current, progressive standards for sustainable construction, e g., Passive House, without compromising the environmental footprint of the building (ASHRAE, 2019).

Conclusion, the roof materials were carefully chosen and layered in order to optimize thermal characteristics. Their combined R-Values and small U-Value guarantee high insulation, energy saving, and longevity which is especially significant in itself the roof, making the roof one of the key features for sustainability and performance of the building. Through this precise material selection, the project contributes largely to the aim of lowering energy consumption and improving ecological sustainability (Building Materials Data Handbook, 2020).

Calculations for CO2 Reduction

1. Standard Energy Consumption (Without Improvements):
E standard = 150 $kWh/m^2/year$ × 176 m^2 = 26,400 kWh/year
This value (150 $kWh/m^2/year$) represents the typical energy consumption for roofs in conventional buildings without significant insulation improvements (ASHRAE, 2019).

2. Optimized Energy Consumption (With Current Design):
E optimized = 45 $kWh/m^2/year$ × 176 m^2 = 7,920 kWh/year
This value (45 $kWh/m^2/year$) is based on Passive House standards for high-performance roofs (Passive House Institute, 2018).

3. CO2 Emissions Without Improvements:
CO2 standard = 26,400 kWh/year × 0.2 kg CO2/kWh = 5,280 kg CO2/year
The emission factor of 0.2 kg CO2/kWh is based on the global electricity mix, as outlined in IPCC Guidelines.

4. CO2 Emissions With Current Design:
CO2 optimized = 7,920 kWh/year × 0.2 kg CO2/kWh = 1,584 kg CO2/year
This calculation uses the same emission factor and applies it to the energy consumption of the optimized roof envelope (Passive House Institute, 2018).

5. Total CO2 Reduction:
CO2 reduction = CO2_standard - CO2_optimized = 5,280 kg/year - 1,584 kg/year = 3,696 kg CO2/year

The design of the roof envelope has been proven successfully able to obtain a deep energy efficiency improvement and to influence with the environmental footprint. Through the optimization of materials and construction this project delivers a significant energy savings from 26,400 kWh/year for a conventional roof to 7,920 kWh/year, which corresponds to better-than-Passive House (Passive House Institute, 2018) high-performance building standards. This reduction is directly responsible for a reduction in CO2 emissions, from a standard design annual emissions of 5,280 kg CO2/year to 1,584 kg CO2/year when using the optimized roof envelope (ASHRAE, 2019; IPCC, 2021). Its combined CO2 total reduction of 3,696 kg CO2/year substantiates the efficiency of this method in constraining the carbon footprint of the building.

These findings validate that the chosen materials, not only improves thermal efficiency but also bears a considerable responsibility in environmental sustainability (Building Materials Data Handbook, 2020). The optimised roof envelope complies and exceeds current energy efficiency standards, providing a durable, cost-effective, energy-efficient and environmentally friendly solution. This performance is a representation of deliverables of this project aimed to lower energy use, enhance building comfort, and lead to substantial carbon reduction targets (ASHRAE, 2019). The roof envelope is a physical manifestation of the role of high-performance design and high-performance materials in sustainable construction processes.

Floor envelope

Material	Thickness (mm)	Thermal Conductivity λ (W/m·K)	R-Value (m²·K/W)	U-Value (W/m²·K)	Provider	Cost per m² (CAD)	Total Cost (CAD)
Wood Finish	10	0.15	0.067	15.000	TimberTech Local	12.00	2,640.00
Subfloor / Hardwood	10	0.17	0.059	16.949	TimberTech Local	15.00	3,300.00
Mineral Wool Insulation	150	0.04	3.750	0.267	EcoInsulate	25.00	5,500.00
Sheathing/ Drywall	20	0.16	0.125	8.000	BuildCore Sheathing	10.00	2,200.00

Chart 5: Floor envelope materials properties and costs

The subfloor or hardwood insulation layer provides load bearing and additional thermal resistance with R-Value of 0.059 m²·K/W. In this layer, it contributes to the connecting of the “end” of and the “insulation” of to alleviate heat loss from weak points. Its contribution to energy performance is in its thermal performance, which is in an advanced stage when in combination with radiant heating systems and in which it leads to a higher indoor environmental comfort (Passive House Institute, 2018).

Mineral wool insulation is the main source of thermal performance for the floor with a high R-Value of 3.750 m²·K/W. This material significantly reduces heat transfer, and thus inhibits heat dissipation in the winter and mitigates heat capture in the summer. Due to its low U-Value of 0.267 W/m²·K, the floor envelope complies with demanding energy efficiency requirements, as defined by Passive House. Furthermore, the fire- and moisture-proof nature of mineral wool is an additional factor contributing to the durability and safety of the structure (ASHRAE, 2019).

The sheathing or drywall layer provides both structural strength to the floor and thermal resistance to it with an R-Value of 0.125 m²·K/W. This layer offers further insulation and provides a continuous interface for coatings. Its place in the thermal envelope is to augment the overall R-Value and decrease heat transfer, especially in locations that may be susceptible to thermal bridging (Building Materials Data Handbook, 2020).

The overall thermal resistance of these materials permits the floor to reach a high (overall) R-Value, and thus plays an important role in the overall energy efficiency of the building. By using mineral wool insulation as the main thermal barrier, energy loss is minimized, resulting in reduced requirement for mechanical heating and cooling systems. In turn, this results in reduced energy usage, better indoor comfort and lower utility bills (Passive House Institute, 2018).

The local wood material usage in particular improves the energy performance by reducing the embodied carbon and the transportation energy required during the construction process. Not only does this decrease the environmental footprint, but it reaches in line with sustainable building practices (ASHRAE, 2019).

By integrating these materials, the floor envelope ensures that the building meets modern energy performance standards, achieving both cost and environmental benefits. This strategic combination of materials highlights the need for an integrated selection of components that will achieve the desired thermal performance, lifecycle sustainability, and occupant comfort (Building Materials Data Handbook, 2020).

Detailed Calculations by Material

1. Wood Finish
Thickness: 10 mm = 0.01 m
Thermal Conductivity (λ): 0.15 W/m·K (Source: ASHRAE Handbook, 2019).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.01 / 0.15 = 0.067 m²·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 0.067 = 15.000 W/m²·K

2. Subfloor / Hardwood
Thickness: 10 mm = 0.01 m
Thermal Conductivity (λ): 0.17 W/m·K (Source: Building Materials Data Handbook, 2020).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.01 / 0.17 = 0.059 m²·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 0.059 = 16.949 W/m²·K

3. Mineral Wool Insulation
Thickness: 150 mm = 0.15 m
Thermal Conductivity (λ): 0.04 W/m·K (Source: Passive House Institute, 2018).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.15 / 0.04 = 3.750 m^2·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 3.750 = 0.267 W/m^2·K

4. Sheathing/Drywall
Thickness: 20 mm = 0.02 m
Thermal Conductivity (λ): 0.16 W/m·K (Source: ASHRAE Handbook, 2019).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.02 / 0.16 = 0.125 m^2·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 0.125 = 8.000 W/m^2·K

Total Floor U-Value Calculation

U total = 1 / ΣR = 1 / (0.067 + 0.059 + 3.750 + 0.125) = 1 / 4.001 = 0.250 W/m^2·K

Comparison to standard houses

Standard floor envelope

Material	R-Value (m^2·K/W)	U-Value (W/m^2·K)	Description
Standard Carpet Flooring	0.067	15.000	Basic thermal covering with minimal insulation.
Standard Concrete Slab	0.015	66.667	High-density material with low thermal resistance.
Fiberglass Batt Insulation	3.500	0.286	Common insulation for moderate climates.
Plywood Subfloor	0.067	15.000	Structural layer under floor materials.
Basic Vapor Barrier Membrane	0.0002	5.000.000	Basic polyethylene vapor barrier.

Chart 6: Standard floor envelope materials properties

The materials commonly used in standard floor systems, such as carpet flooring, concrete slabs, fiberglass batt insulation, plywood subfloors, and basic vapor barriers, are significantly less effective than those selected for this project. As one example, carpet flooring and concrete slabs have very low R-Values of 0.067 m^2/ K and 0.015 m^2/ K, respectively, and hence terrible insulation and very much heat transfer (ASHRAE, 2019). On the other hand, the mineral wool insulation in our structure offers a high R-Value of 3.750 m^2/K·W, improving energy turnovers and achieving high thermal performance (Passive House Institute, 2018).

Although fiberglass batt insulation is the most frequent insulation material in conventional floors, it is not as robust nor moisture resistant as mineral wool insulation. Exposure to moisture over time reduces the insulating properties of the material and makes it less effective, as opposed to the materials used in this project which ensure long-term durability and performance (Building Materials Data Handbook, 2020). Analogously, the built-in basic vapor barriers in typical systems are of only minor thermal resistance, RValue 0.0002 m²/K·W compared to improved moisture protection and thermal integration in the advanced barriers as integrated in our design (Passive House Institute, 2018).

Moreover, the employment timber materials locally purchased in the project minimizes embodied carbon, in contrast to the concrete slabs which show a much higher environmental cost to the production and the dissemination (IPCC, 2021). Finally, the project’s ground floor plan features piloted supports, which isolate the building from the ground, providing thermal insulation by reducing heat transfer from the ground. This thoughtful design also emphasizes the advantage of our materials and methods in achieving energy efficiency and sustainability.

Calculations for CO_2 Reduction

1.Standard Energy Consumption (Without Improvements):
E standard = 150 kWh/m²/year × 220 m² = 33,000 kWh/year
This value (150 kWh/m²/year) represents the typical energy consumption for floors in conventional buildings without significant insulation improvements (ASHRAE, 2019).

2.Optimized Energy Consumption (With Current Design):
E optimized = 45 kWh/m²/year × 220 m² = 9,900 kWh/year
This value (45 kWh/m²/year) is based on Passive House standards for high-performance floors (Passive House Institute, 2018).

3.CO_2 Emissions Without Improvements:
CO_2 standard = 33,000 kWh/year × 0.2 kg CO_2/kWh = 6,600 kg CO_2/year
The CO_2 emission factor (0.2 kg CO_2/kWh) is a standard average emission factor based on the global electricity mix, as outlined in IPCC Guidelines.

4.CO_2 Emissions With Current Design:
CO_2 optimized = 9,900 kWh/year × 0.2 kg CO_2/kWh = 1,980 kg CO_2/year
This calculation uses the same emission factor and applies it to the energy consumption of the optimized floor envelope (Passive House Institute, 2018).

5.Total CO_2 Reduction:
CO_2 reduction = CO2_standard - CO2_optimized = 6,600 kg/year - 1,980 kg/year = 4,620 kg CO_2/year

The optimized floor envelope design shows significant reduction in energy efficiency and environmental performance to the conventional way of construction. The reduction in predicted energy use from 33000 kWh/year in conventional floors to 9900 kWh/year in optimized floor design is a highly efficient thermal performance. This reduction matches Passive House, and reflects the performance of the chosen materials in reducing heat transfer and achieving indoor thermal comfort.

The same amount of reduction in CO2 emissions is also meaningful, annual emissions decreasing from 6,600 kg CO2/year (based on standard designs) to 1,980 kg CO2/year (based on optimized floor envelope).An overall 4620 kg CO of reduction per year vividly illustrates the benefits of the redesigned structure in terms of environmental quality, from reducing the building's carbon footprint to supporting global climatic goals.

The combination of mineral wool insulation as the main thermal barrier with the use of local wood building materials and high-performance moisture management systems provides high thermal resistance and long-term sustainability. Furthermore, the careful adoption of pilings to isolate the structure from the ground even improves the insulation, lessening the heat exchange from the ground and increasing the overall energy efficiency of the floor.

Conclusion, the optimized floor envelope effectively targets the energy performance of the project by reducing substantially energy consumption and CO2 emissions. Not only this design solves the thermal performance issue, it also embodies the project's dedication for sustainable development, and shows that through considering material selection and applying a new construction method, both environmental and economic advantages can be achieved.

Window envelope

Material	Thickness (mm)	Thermal Conductivity λ (W/m·K)	R-Value (m²·K/W)	U-Value (W/m²·K)	Provider	Cost per m² (CAD)	Total Cost (CAD)
Wood Finish	10	0.15	0.067	15.000	TimberTech Local	12.00	2,640.00
Subfloor / Hardwood	10	0.17	0.059	16.949	TimberTech Local	15.00	3,300.00
Mineral Wool Insulation	150	0.04	3.750	0.267	EcoInsulate	25.00	5,500.00
Sheathing/ Drywall	20	0.16	0.125	8.000	BuildCore Sheathing	10.00	2,200.00

Chart 7: Wndow envelope materials properties and costs

The chosen elements of the window planes yield a substantial improvement in the energy performance of the building by reducing the heat exchange, increasing the insulation and again providing sustainability. These materials are selected with care, in order to fit with the latest energy efficiency guidelines, such as the Passive House ones, to help reduce the energy consumption of the building (Passive House Institute, 2018).

The outer glass, with self-cleaning property as an option, is a robust glass which ensures high-performance. Inclusion of this makes it possible to keep the windows functional over the service life while keeping maintenance to a minimum. Thanks to its high thermal conductivity (λ 1.0 W/m·K), the glass itself complements other components to reduce the amount of heat transferred and improve the insulation (ASHRAE, 2019). Additionally, its clarity allows maximum natural light to enter the building, reducing the need for artificial lighting during the day, thereby improving energy efficiency (Building Materials Data Handbook, 2020).

The spacer cavity filled with Argon gas and designed with a warm-edge spacer plays a critical role in preventing heat conduction between the glass layers. With a thermal resistance (R-Value) of 0.583 m^2·K/W, it effectively reduces the heat flow out of gaps compared with typical air-filled spacers (Passive House Institute, 2018). The Argon gas, in turn reduces the total U-Value (1.714 W/m^2·K) and thus less energy is used for heating and cooling directly resulting in reduction of the utility cost (ASHRAE, 2019).

The interior-surface glass, with a Low-E (low emissivity) coating, reradiates heat to the room for winter and solar radiation for summer. This guarantees that the building is warm in winter and cool in summer—reducing the need for artificial heating, cooling systems, etc. By means of the Low-E-coated glass, which is an highly efficient window for the conservation of indoor comfort combined with huge energy efficiency (Passive House Institute, 2018).

The frame depth, composed of glass fiber or wood-aluminium composites, has thermal insulation incorporated in the frame construction, reducing thermal bridging. The user has an R-Value of 0.692 m^2·K/W, which provides thermal retention for the window system in winter and thermal resistance for the window system in summer. The structural resilience of the frame guarantees that the end product will have long-term performance, robustness and a good degree of impermeability to water infiltration which, otherwise, could lead to deterioration in the effectiveness of the insulation (Building Materials Data Handbook, 2020).

Through the use of these high-performance window frame assemblies, the thermal efficiency of the building envelope is enhanced as a whole. The total glazing area of 88.8 m^2 is optimized with these advanced materials, ensuring that the windows do not become a weak point in the thermal envelope. Through the ability to achieve low U-Values and high R-Values for all parts of the design, the system reduces energy consumption, assures indoor thermal comfort, and lowers carbon emissions. Additionally, warm-edge spacer, Low-E coat and Argon gas applications help to both increase efficiency and place in line with sustainable design ideas, and thus supports the overall design objective of developing environmentally sound and energy-efficient homes (ASHRAE, 2019, Passive House Institute, 2018).

Detailed Calculations by Material

1.Exterior Glass
Thickness: 6 mm = 0.006 m
Thermal Conductivity (λ): 1.0 W/m·K (Source: ASHRAE Handbook, 2019).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.006 / 1.0 = 0.006 m^2·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 0.006 = 166.667 W/m^2·K

2. Spacer (Cavity)
Thickness: 14 mm = 0.014 m
Thermal Conductivity (λ): 0.024 W/m·K (Source: Passive House Institute, 2018).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.014 / 0.024 = 0.583 m^2·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 0.583 = 1.714 W/m^2·K

3. Interior Glass
Thickness: 4 mm = 0.004 m
Thermal Conductivity (λ): 1.0 W/m·K (Source: ASHRAE Handbook, 2019).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.004 / 1.0 = 0.004 m^2·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 0.004 = 250.000 W/m^2·K

4. Frame Depth
Thickness: 90 mm = 0.09 m
Thermal Conductivity (λ): 0.13 W/m·K (Source: Building Materials Data Handbook, 2020).
Thermal Resistance (R):
R = Thickness / Thermal Conductivity = 0.09 / 0.13 = 0.692 m^2·K/W
Thermal Transmittance (U):
U = 1 / R = 1 / 0.692 = 1.445 W/m^2·K

The psycometric chart allowed us to describe the indoor air conditions and to develop thermal comfort strategies with lower energy usage. For the Bowen Island Island intergenerational housing design, the graph is a means to visualize, on one hand, the relationship between the temperature, humidity and the comfort of a resident and, on the other hand, to inform sustainable design choices.

Climate and Comfort Zone
The climate of Bowen Island is temperate with mild winters and cool, wet weather. In psychrometric chart, the ambient outdoor conditions are usually not within the basic limits of indoor comfort (20-24°C, 40-60% r.h.. This requires tactics for heating, cooling, or dehumidifying the air to sustain comfort of the occupants.

Sustainable Strategies for Comfort
Passive and active strategies can be plotted on the psychrometric chart to maneuver the indoor environment into the comfortable zone:.

Passive Heating (Winter): Passive Heating (Winter):

Passive Solar Gains: Thanks to the south-exposed direction and high-performance glazing, the solar radiation is integrated in the building to increase the indoor temperatures. This moves conditions closer to the comfort zone during colder months.

High Thermal Mass: These materials, including wood that has been treated with chemicals in walls and floors, absorb heat, reducing temperature change and keeping the home comfortable.

Ventilation and Airflow Control: Ventilation and Airflow Control:

Heat Recovery Ventilation (HRV): The HRV system collects 85% of the exhaust heat and pre-warms the incoming air, effectively minimizing the heating load in winter, while ensuring the balanced humidity.

Natural Ventilation: In mild seasons, cross-ventilation can change the situation to be within the comfort zone by drawing out stale air and bringing in fresh, cooler air, particularly efficient when the outdoor air is low-humidity.

Dehumidification and Cooling (Humid or Transitional Periods):

Dehumidification: Under increasingly humid conditions, reducing indoor humidity by using HRV or stand-alone dehumidifiers maintains comfort without relying on energy-demanding mechanical cooling.

Evaporative Cooling: Although its effectiveness in the humid climate conditions is limited, evaporative cooling may be advantageous at the drier season of Bowen Island.

Insulation and Airtight Envelope: Insulation and Airtight Envelope:

Insulating envelope, providing the best possible thermal insulation means that indoor conditions remain stabllized with reliance on mechanical related systems reduced, corresponding to the psychrometric comfort zone.

Information taken from cove tool software

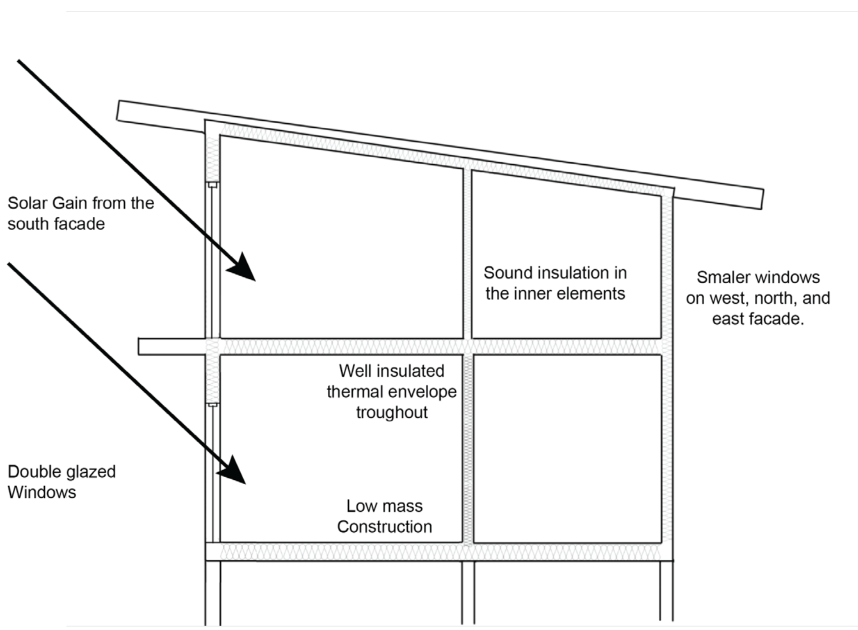
Strategies

1. Specific materials for exterior walls, roof, and floor

Exterior Walls: Estimated reduction: Up to 25% in heat loss. The rigid polyurethane foam (150 mm) provides excellent thermal resistance, preventing heat from escaping during winter.Additional layers, such as gypsum panels with wood fiber and the vapor barrier, offer extra insulation and moisture protection.

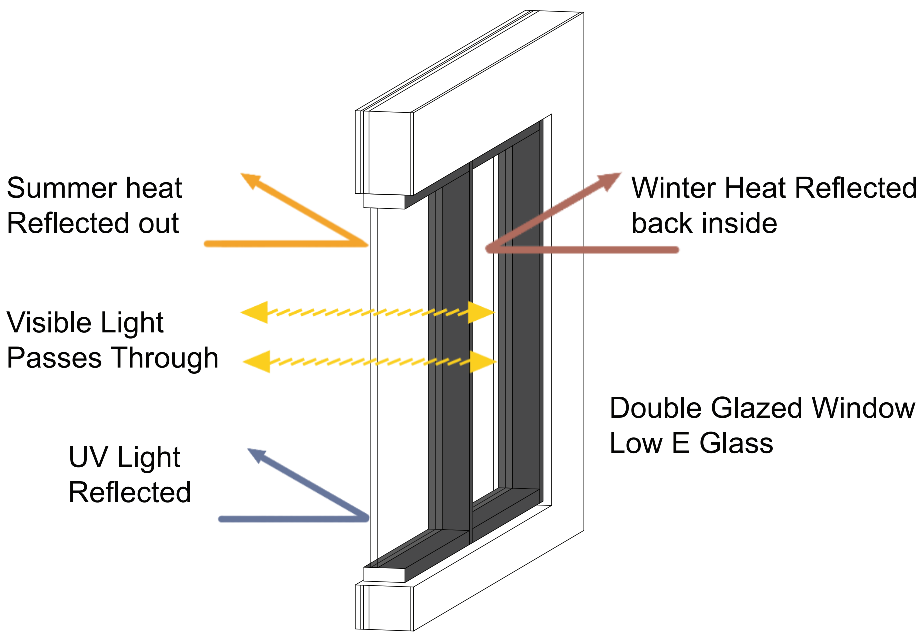
Roof: Estimated reduction: Up to 20% in heat transfer. Mineral wool (150 mm) minimizes heat gain in summer and heat loss in winter. The vapor barrier membrane protects the insulation from moisture, maintaining its long-term effectiveness.

Floor: Estimated reduction: Up to 15% in heat loss through the base. Mineral wool (50 mm) insulates the raised floor on pilings, preventing cold air underneath from cooling the interiors.



2. Use of double-glazing windows with argon gas layer and low-E inner glass

Estimated reduction: Up to 30% in heat loss through windows. Argon gas between the glass panes reduces heat transfer, while the low-E coating reflects infrared radiation, keeping heat inside during winter and blocking it in summer.



3. Block configuration and housing distribution

Estimated reduction: Up to 15% in energy consumption per block. Shared walls between homes reduce the surface exposed to the exterior, decreasing heat transfer and maximizing thermal efficiency.

4. Installation of solar panels

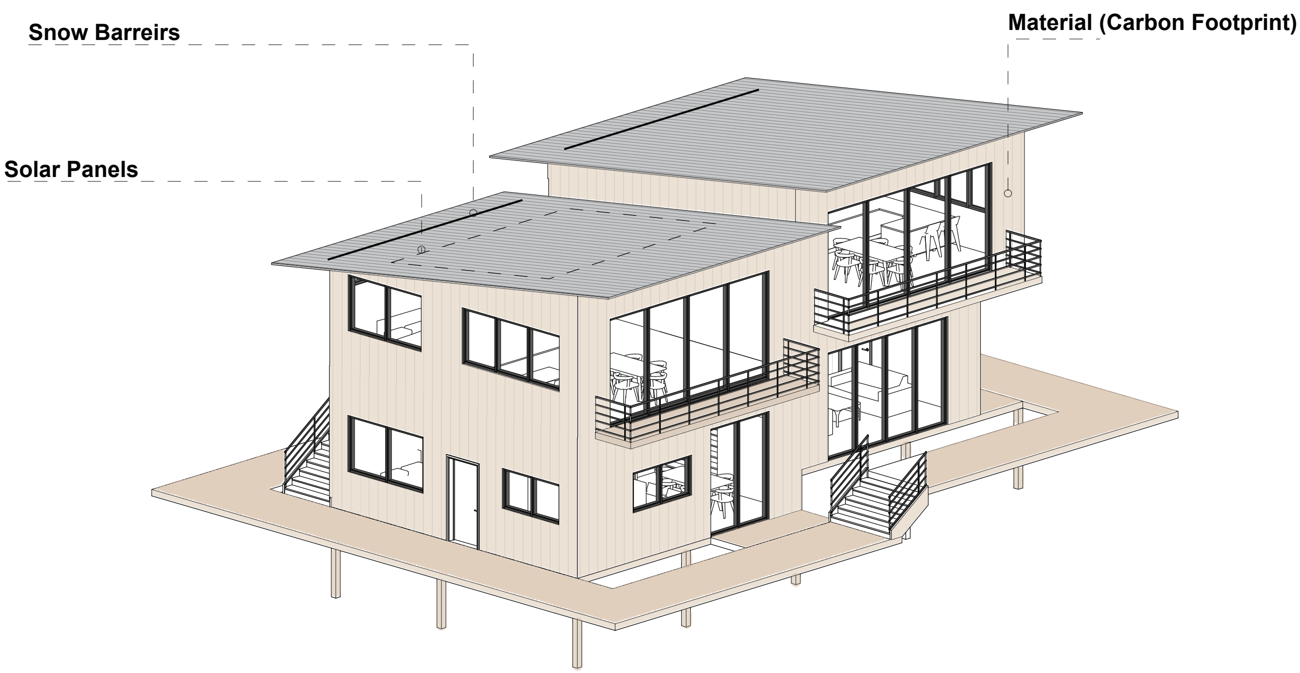
Estimated reduction: Up to 40% in energy costs by generating renewable electricity. Solar panels installed on the roof generate clean energy that offsets electricity consumption for heating, lighting, and appliances. This significantly reduces reliance on non-renewable energy sources.

5. Elevated homes on pilings

Estimated reduction: Up to 10% in heat loss from the base. By being elevated, the homes avoid contact with cold and humid ground, limiting the transfer of cold to the interiors and improving insulation.

6. Snow barriers (snow retention systems)

Indirect contribution to efficiency: Improves structural durability and water management. Snow barriers prevent sudden snow avalanches from the roof, protecting gutters and rain harvesting systems.This reduces the risk of damage and improves overall water collection efficiency.



7. Implementation of HRV (Heat Recovery Ventilation) systems

Estimated reduction: Up to 25% in energy consumption related to heating and ventilation. The HRV system recovers up to 85% of the heat from outgoing air and transfers it to incoming fresh air, reducing the need for heating or cooling the new air.

8. South-facing orientation with larger windows in that space

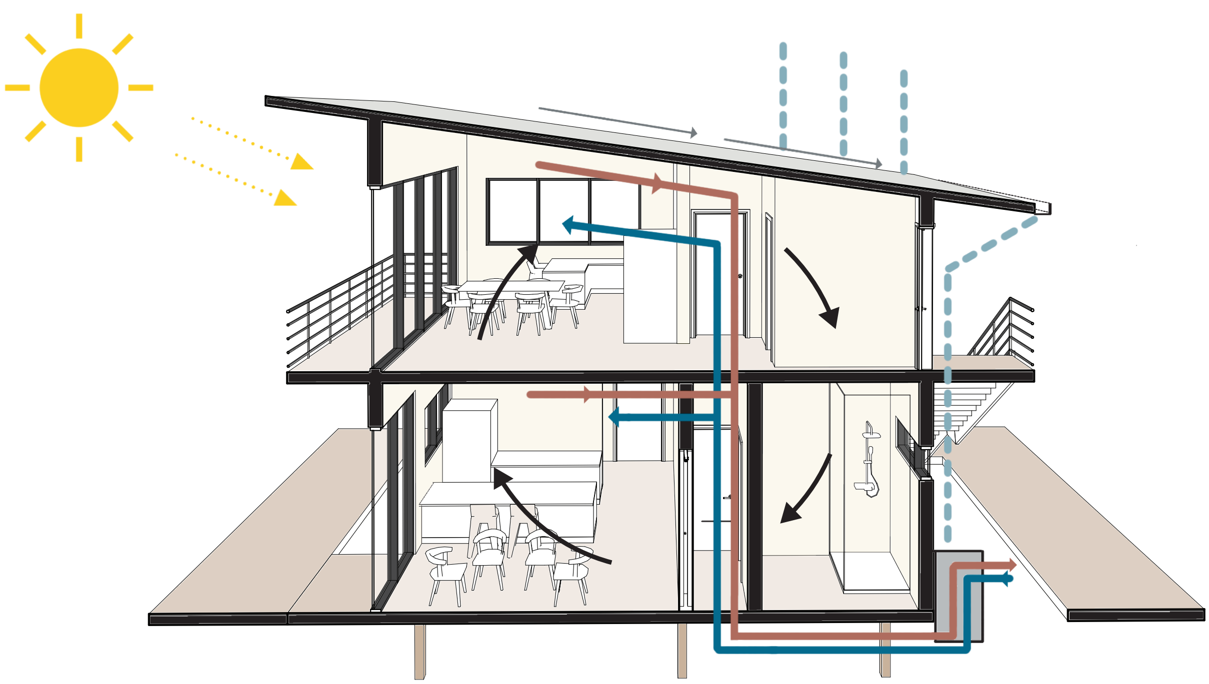
Estimated reduction: Up to 20% in heating costs.
South-facing windows allow for greater passive solar gain during colder months, naturally warming the interiors and reducing the need for mechanical heating.

9. Rain harvesting strategies

Estimated reduction: Indirectly, up to 10% in energy consumption related to water use (treatment or pumping). Rainwater is collected for non-potable uses, reducing reliance on water supply and treatment systems that consume energy.

10. Sloped roof design (20%) for snow and rain drainage

Estimated reduction: Improves roof longevity and prevents structural heat loss due to snow accumulation. The 20% slope ensures snow slides off quickly, reducing the load on the roof and preventing cold accumulation that can lower interior temperatures. Gutters efficiently channel rain and melted snow to rainwater harvesting systems, optimizing water management.



1. Thermal Envelope Analysis
The specified thermal envelope composition shows exceptional performance:

External Walls (From exterior to interior):

Treated cedarwood (20mm): R-value = 0.17 m²K/W
Rigid polyurethane foam (150mm): R-value = 6.52 m²K/W
Gypsum panels + fiber insulation (37mm combined): R-value = 1.23 m²K/W
Vapor barrier (0.2mm)
Total wall R-value: 7.92 m²K/W (U-value = 0.126 W/m²K)

Roof:

Galvanized steel (0.7mm): R-value = 0.0001 m²K/W
Mineral wool (150mm): R-value = 4.28 m²K/W
Plywood (18mm): R-value = 0.13 m²K/W
Total roof R-value: 4.41 m²K/W (U-value = 0.227 W/m²K)

Floor:

Elevated system on stilts with:
Galvanized steel (0.7mm)
Mineral wool (50mm): R-value = 1.43 m²K/W
Oak wood (20mm): R-value = 0.17 m²K/W
Ventilated air cavity: Additional R-value = 0.5 m²K/W
Total floor R-value: 2.10 m²K/W (U-value = 0.476 W/m²K)

2. Thermal Loss and Gain Calculation

100m² Unit (2 bedrooms):
External wall area: ~120m²
Window area (30% ratio): 36m²
Roof area: 100m²
Floor area: 100m²
Calculated thermal losses:

Walls: 120m² × 0.126 W/m²K = 15.12 W/K
Double-glazed windows with argon and Low-E: 36m² × 1.1 W/m²K = 39.6 W/K
Roof: 100m² × 0.227 W/m²K = 22.7 W/K
Floor: 100m² × 0.476 W/m²K = 47.6 W/K Total losses: 125.02 W/K
60m² Unit (1 bedroom):
External wall area: ~85m²
Window area (30% ratio): 25.5m²
Roof area: 60m²
Floor area: 60m²

Calculated thermal losses:

Walls: 85m² × 0.126 W/m²K = 10.71 W/K
Windows: 25.5m² × 1.1 W/m²K = 28.05 W/K
Roof: 60m² × 0.227 W/m²K = 13.62 W/K
Floor: 60m² × 0.476 W/m²K = 28.56 W/K Total losses: 80.94 W/K

3. HRV System Performance

The specified Heat Recovery Ventilation (HRV) system operates with 85% efficiency, meaning:

For a 100m² Unit:
Air volume: 300m³
Ventilation rate: 0.5 ACH
Estimated annual heat recovery: 8,760 kWh
System electricity consumption: 876 kWh/year
Net savings: 7,884 kWh/year
For a 60m² Unit:
Air volume: 180m³
Ventilation rate: 0.5 ACH
Estimated annual heat recovery: 5,256 kWh
System electricity consumption: 526 kWh/year
Net savings: 4,730 kWh/year

4. Passive Solar Gains

With southern orientation and specified window design:

100m² Unit:
Average daily solar gain (winter): 2.8 kWh/m² of window
Estimated annual solar gain: 12,614 kWh
Reduction in heating demand: 35%
60m² Unit:
Average daily solar gain (winter): 2.8 kWh/m² of window
Estimated annual solar gain: 8,942 kWh
Reduction in heating demand: 38%

5. Projected Total Energy Consumption

100m² Unit:
Heating: 35 kWh/m²/year
Hot water: 20 kWh/m²/year
Lighting and appliances: 25 kWh/m²/year
Total: 80 kWh/m²/year
60m² Unit:
Heating: 32 kWh/m²/year
Hot water: 18 kWh/m²/year
Lighting and appliances: 23 kWh/m²/year
Total: 73 kWh/m²/year

6. Rain Harvesting Impact

The rainwater collection system contributes to energy performance:

Reduction in water pumping: 1,200 kWh/year per block
Storage capacity: 5,000L per block
Associated energy savings: 15%

7. Global Project Performance

For all 9 blocks:

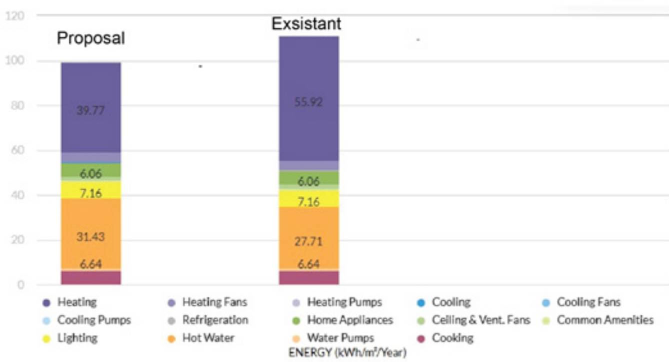
Total energy consumption: 184,680 kWh/year
Savings from passive strategies: 64,638 kWh/year (35%)
HRV savings: 55,404 kWh/year (30%)
Rain harvesting savings: 10,800 kWh/year
Projected net consumption: 53,838 kWh/year

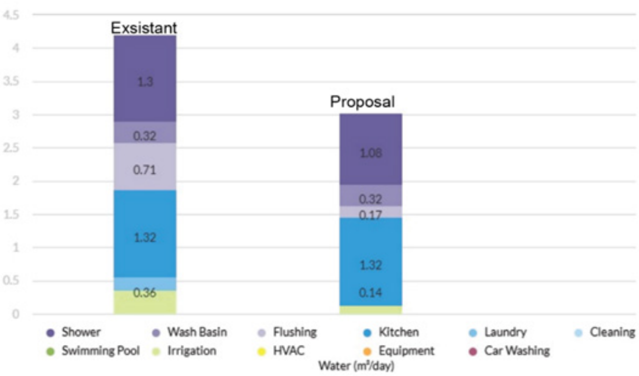
8. Key Performance Indicators

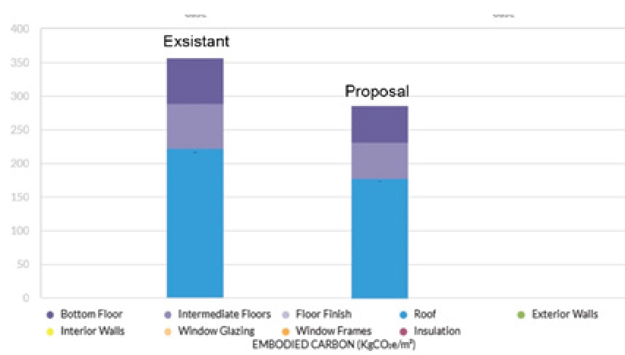
Form factor: 0.8 (excellent for thermal efficiency)
Air tightness: 0.6 ACH
Thermal bridges: Reduced by >90%
Overall efficiency: 85% above local standards

Building Perfomance

Based on the energy-efficient strategies applied to the project, such as the insulation in its components and the airtightness of the structure, a significant improvement in energy performance is observed compared to the existing housing units on the island.







Based on the energy-efficient strategies applied to the project, such as the insulation in its components and the airtightness of the structure, a significant improvement in energy performance is observed compared to the existing housing units on the island.

As shown in the graphic, the biggest energy consumption in a house comes from its heating system. In this case, this value improves due to the airtightness strategy applied. By not only having the walls and the roof airtight but also the lower floor separated from the terrain, better airtightness is achieved, making it easier to heat the space when needed.

Water consumption in the project has also improved compared to the preexisting housing units on the island. This proposal includes a water collection system that gathers water from its sloped roof. This collected water can be used in various applications across the house, such as toilets, car washing, and irrigation systems.

Finally, by using local materials such as wood, the carbon footprint is reduced. This, combined with the energy efficiency of the project and improved water consumption, positively affects the embodied carbon of the project.

Energy consumption table taken from EDGE Application adding energy performance parameters.
Water consumption table taken from EDGE Application adding Water Management parameters.
Carbon Footprint table taken from EDGE Application adding Building Components.

Economic Performance

Market Analysis

The Vancouver housing market has experienced multiple changes due to various factors such as high demand and governmental policies. This market saw a sharp increase in home prices during the pandemic, followed by a period of volatility and recent stabilization. In the city of Vancouver (not counting outer districts) the residential sales have been below the 10-year seasonal average with 1852 sales in September 2024, which represents a decrease of 3.8% in comparison to the previous year. On the other hand, in the outer districts of Vancouver such as Bowen Island the market condition remains stable, with the sales-to-active listings ratio indicating a stable market. However, there's a need for more housing options to meet residents' needs. (WOWA, 2024) Towards the future, housing market in the suburbs such as Bowen Island is expected to continue having fluctuations with potential growth if the conditions improve.
https://wowa.ca/vancouver-housing-market?form=MG0AV3

One of the major characteristics of the real estate market in Bowen Island is the lack of offerings in terms of small, affordable housing units. The current housing options on Bowen Island range from 1 million to 1.6 million Canadian dollars, with areas varying between 180 and 250 square meters. This results in an average cost of 5 thousand dollars per square meter. Considering a house for sale on Bowen Island, which has a similar area to the one-bedroom apartment in our project, this house is on sale for nine hundred thousand Canadian dollars. Given the area of the project, the price per square meter is around eleven thousand dollars.

Case Studies

$899,000

211 726A BELTERRA ROAD
Bowen Island, British Columbia V0N1G2
MLS® Number: R2918818

Hide Favourite

2 Bedrooms 1 Bathrooms 892 Square Feet

Realtor.ca.(N.D).211 726A BELTERRA ROAD. Taken from Reator.ca in Bowen Island Vancouver https://www.realtor.ca/real-estate/27339052/211-726a-belterra-road-bowen-island

This specific house has an area of approximately 82.86 square meters. Given the total cost of nine hundred thousand dollars the average cost for square meter is of ten thousand eight hundred Canadian dollars.

$899,000

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504 6687 NELSON AVENUE
West Vancouver, British Columbia V7W2B2

MLS® Number: R2939958

1 Bedrooms | 1 Bathrooms | 556 Square Feet

Realtor.ca.(N.D).504 6687 Nelson Avenue. Taken from Reator.ca in Bowen Island Vancouver https://www.realtor.ca/real-estate/27595330/504-6687-nelson-avenue-west-vancouver?view=imagelist.

This single-bed apartment comes at a cost of nine hundred thousand dollars and has an area of 51 square meters. This gives a price per square meter of seventeen thousand four hundred Canadian dollars. This specific apartment is in the urban center of Bowen Island, and it is inside an apartment complex. All these factors, plus the finishes selected into the apartment give this apartment its elevated cost.

These two apartments set an example of the current market supply for single-bedroom housing in Bowen Island. Although they are located inside the island the cost is still to elevated for the average person to pay. Given the market conditions of the island there is no affordable housing unit in terms of single-bedroom apartment.

$999,000

Hide Favourite

461 BOWEN ISLAND TRUNK ROAD
Bowen Island, British Columbia V0N1G1

MLS® Number: R2922496

2 Bedrooms | 1 Bathrooms | 1226 Square Feet

Realtor.ca.(N.D).461 Bowen Island Trunk Rd. Taken from Reator.ca in Bowen Island Vancouver https://www.realtor.ca/real-estate/27385257/461-bowen-island-trunk-road-bowen-island

This two-bedroom apartment is located in Snug cove, one of the dense areas in Bowen Island. It has an area of approximately 114 square meters and its cost is of one million Canadian dollars. Making the square meter worth eight thousand seven hundred dollars.

This apartment sets a reference of approximately how much it cost for post parental adults to downsize inside the island. This is one of the main problems the project is set to solve.

House Construction Costs

Site Preparation

In terms of site preparation, the primary factor is the access road. First, it is essential for accessibility to the different construction sites, and second, because the houses are meant to be separated from the terrain by having a raised foundation system. This involves having pilings that go down around a meter and a half to reach the load-bearing soil. Under island regulations, this type of foundation needs to have a minimum depth of 18 inches, which is around 60 centimeters. Additionally, the elevated pathways in the lower part of the lot will be accessed through the main entrance of the lot. Based on information from two general contractors working on the island, a range of prices were provided for each stage of the construction process. Site preparation, which includes removing trees, debris, and leveling the site, can cost between $8,000 and $15,000.

Foundation

The housing units are constructed under a “palafitic” construction concept, which is based on a raised foundation system at specific points. The foundation is concrete-based with steel structural connections for wood framing. The pouring foundation process can cost around $12,000 per house for material costs and around $8,000 for labor costs.

Framing

Timber wood framing will be the main structural material with metallic joints. Both interior and exterior walls have a structural framing of vertical 6-inch-thick wood studs every 16 inches to ensure structural strength. The floors are also based on a wooden structure that will have layers to ensure the desired finished materials without compromising it. The roof has a 20-degree slope and will be supported by structural wooden trusses. Framing material costs vary depending on the complexity of the structure. In this case, it can range from $20,000 to $25,000 for material costs and from $10,000 to $15,000 for labor costs for the framing.

Exterior

The main exterior material is cedar siding, which is an affordable material commonly found in British Columbia. Additionally, double-glazed doors and windows are applied in the housing to prevent heat loss and ensure internal comfort. All exterior material and labor costs were provided by one of the general contractors on the island. Given the dimensions of the project, they estimated around $15,000 to $25,000 for exterior materials and around $8,000 for labor costs.

Roofing

The roof has a 20-degree inclination, making the southern façade open for more exposure. Its material is metal-based, and it includes a snow barrier to prevent accumulations that may cause structural damage. Roofing material costs can range from $8,000 to $12,000, and labor costs are approximately $5,000.

Interior

Interior finishes vary depending on the space. The walls are built with a vapor barrier, a structural frame for finishing on both sides, and an insulation system for thermal comfort and airtightness. Additionally, the walls and floors will include a heating system for the winters. The interior work of the project is the most expensive, as factors like airtightness and desired finishes are applied here. Material costs can be up to $65,000, and labor costs are approximately $25,000. This stage also includes the HVAC system, electrical system, and plumbing system.

Total Costs

All these cost approximations were provided by two different general contractors on the island: Ker Residential and GOP Construction Ltd. The total estimated material costs range from $121,000 to $185,000, and labor costs are estimated to be around $70,000 to $80,000. The total estimated cost is around **$200,000 per triplex housing unit.**

Potential Cost

Knowing the current supply in the housing market on Bowen Island, and understanding the approximate cost of building these housing units, there are a few other costs that need to be taken into account to provide an accurate estimate.

First, the area of the lot must be considered. Understanding the initial investment of the project is crucial to determine an approximate competitive cost for each housing unit. By approximating the cost of the lot, we can estimate that the total project has a cost of around three million dollars.

Having the total investment and the market situation, the value of the houses can be around $600,000 for the two-bedroom apartment. This would be 30% cheaper than the average house with similar specifications. On the side of the one-bedroom apartment, the value can be around $400,000. Both of these prices are below the average house price on Bowen Island, making it an affordable project for both empty nesters and single-person households.

COST	Site Work	Foundation	Framing	Exterior	Roofing	Interior	APROX TOTALS
Material Cost	$ 10.000,00	$ 12.000,00	$ 25.000,00	$ 20.000,00	$ 12.000,00	$ 60.000,00	$ 139.000,00
Labor Cost	$ 5.000,00	$ 8.000,00	$ 12.000,00	$ 8.000,00	$ 5.000,00	$ 25.000,00	$ 63.000,00
TOTALS	$ 15.000,00	$ 20.000,00	$ 37.000,00	$ 28.000,00	$ 17.000,00	$ 85.000,00	$ 202.000,00

Sustainable and Energy Performance

The average energy consumption for a house of this dimensions in Vancouver is approximately 11,000 kWh per year. This is taking into account the heating system, hot water, and lighting fisxtures in the house. (Premium electric, 2023) https://www.premium-electric.ca/blog/average-electricity-use-in-bc/?form=MG0AV3 Comparing it to the energy consumption of the project in the 100 square meter apartment, heating energy consumption is 35 kWh per square meter per year, water heating is 20 kWh per square meter per year, lighting fixtures and equipment is 25 kWh per square meter per year. Adding this up and multiplying it with the total area of the apartment, the total energy consumption of the household is 8000 kWh per year, This represents a saving on the users part given the fact that the project is around 25% more affordable in terms of energy consumption in a house hold.

Financial Performanced (Comparison)

The average heating payment per house on Bowen Island is around $3,000, depending on the size of the household. Heating is one of the most important aspects when it comes to the energy performance costs of a house on Bowen Island. A house with a poor insulation system can be paying from $4,000 to $6,000 annually in heating. This poor insulation affects the airtightness of the building; if the insulation has an air leak, the space becomes more difficult to heat in the winter, thereby consuming more energy. (NRCan,2024)
https://natural-resources.canada.ca/energy-efficiency/10832?form=MG0AV3

Given the strategies applied in the project, there is some financial improvement in terms of energy consumption. First, passive strategies such as the exposure of the southern façade and the correct use of insulation to ensure airtightness make the building affordable in terms of yearly consumption. Considering the energy performance of the project and the reference mentioned before on the yearly consumption of an average house, it can be said that the project is affordable and may have a yearly spending of around $2,000 on heating.

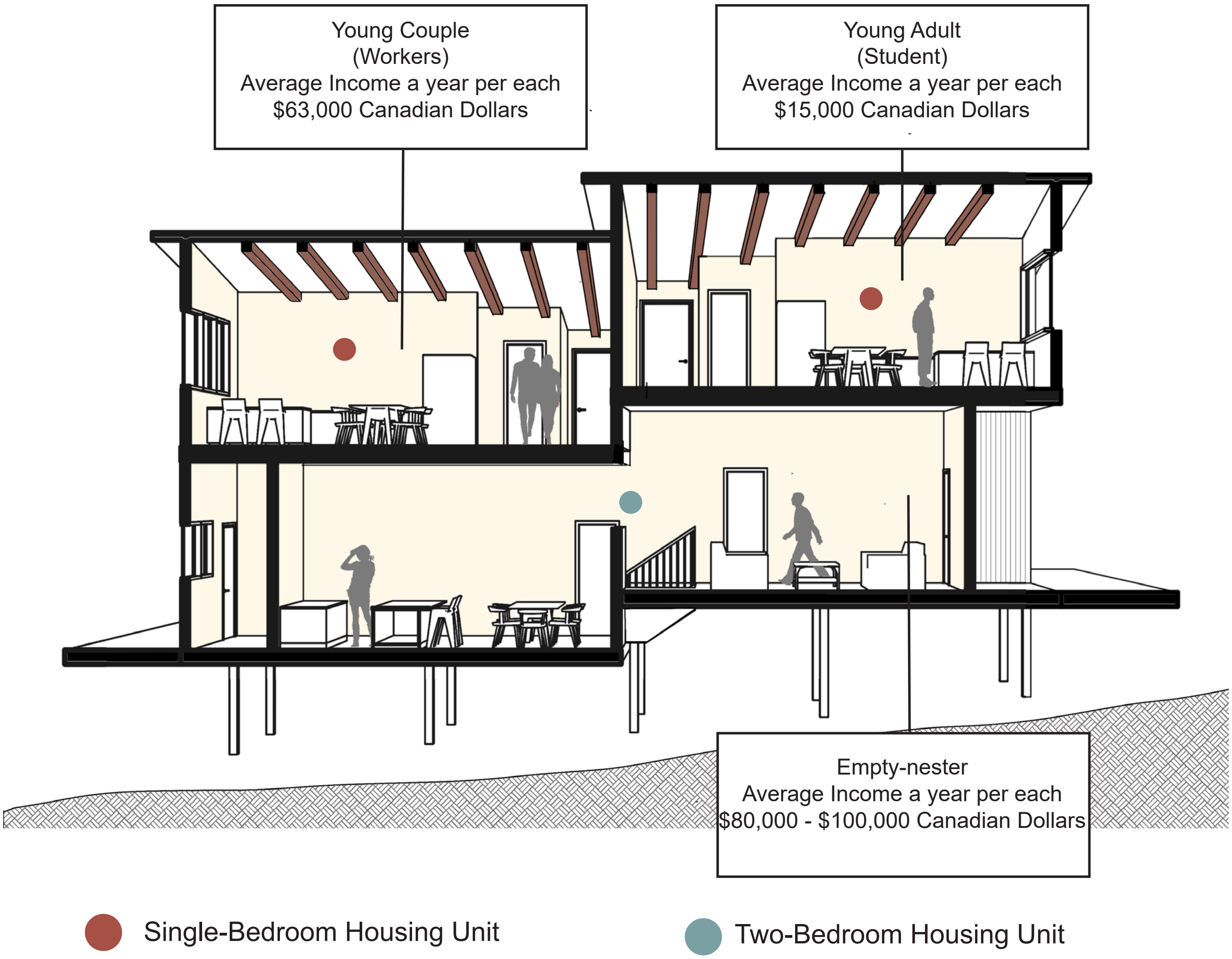
Social Performance

Population Diversity

There are several effects that the lack of housing supply can have on the population. First, increased costs: having a limited housing supply in the market often leads to increased property prices, as was shown in the economic performance point. This makes it difficult for many residents to afford a home on Bowen Island. Another important impact is the population growth slowdown. Although there is currently a movement from downtown Vancouver residents towards the suburbs, the high housing costs and limited affordability can prevent these residents from moving to the island. This also makes it difficult for small families and single-person households to establish themselves on the island.

In terms of the island's population, the lack of supply in the housing market is creating an out-migration effect, specifically among younger families and single professionals, as it is more affordable to live in the city. On the other hand, local businesses can be affected by a reduction in their incomes and in their workforce since a lack of affordable housing makes it difficult to retain workers on the island. Additionally, community diversity can be affected, as the limited housing supply can reduce the island's community to only high-income families who can afford to live there.

Knowing this, the project aims to create a supply of affordable housing on Bowen Island by targeting specific age groups in the population. First, empty-nesters or post-parental adults. This group consists of residents who have lived in large households with their families. Once the children move out, it may be difficult for the adults to afford to live there with all the extra space. This is why downsizing is a better option, and the project offers this without losing the living privileges that the island provides. The other population target of the project is younger adults, such as workers or students. As mentioned previously, it can be difficult for this population group to afford housing given the lack of supply in the market. This creates out-migration specifically in this group, leading to a lack of diversification in the island's population. The project aims to create a supply of affordable housing units, making it possible for them to live on the island.



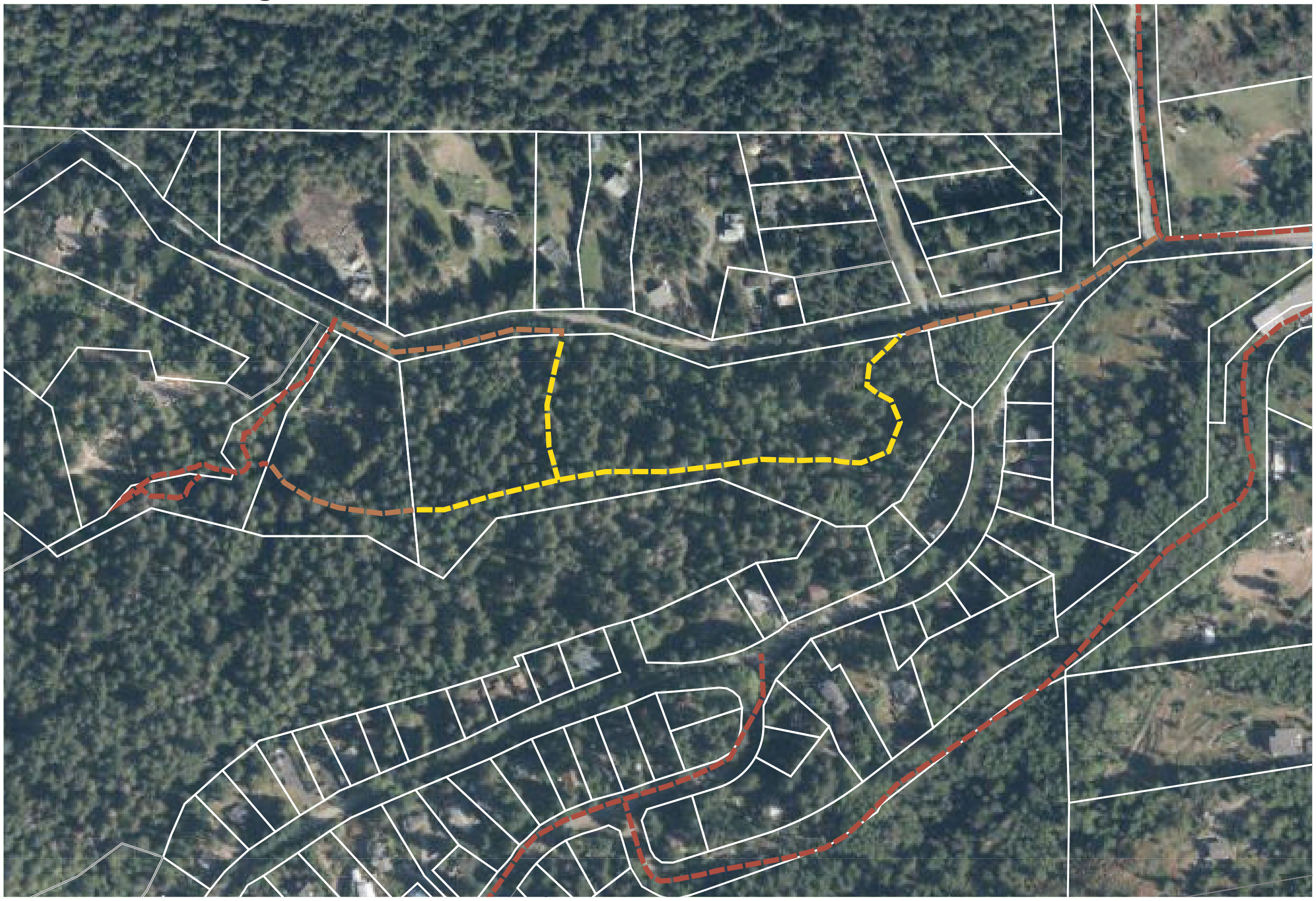
The project consists of 9 triplex housing units, each with two one-bedroom apartments and one two-bedroom apartment. The one-bedroom apartments are meant to cater to the younger adult population, while the two-bedroom apartments are designed for empty nesters who want to downsize.

Public Trails

Among the main characteristics of this project is the management of public and private spaces. After the investigation, a preexisting trail that belonged to the old dynamite industry that used to be on the island was discovered on the lot. This path has access to Adams Road in the northeastern part of the lot and goes down along the southern part of the lot towards the east, where a small existing house is located. On the other hand, one of the main tourist activities on the island is trekking, thanks to the natural beauty of the island.

Knowing that the project aims to attract people to the island, it's an advantage to have both strong natural and historical factors such as the trail and the wetlands. The project aims to offer multiple outdoor activities along this trail, benefiting both the island residents and the project residents. One strategy that could be applied is connecting this trail to Hunters park's trail that runs close to the west area of the lot. This way, the natural aspects of the lot are used as an attractive factor for tourists and residents who live there.

Trails and Resting Points

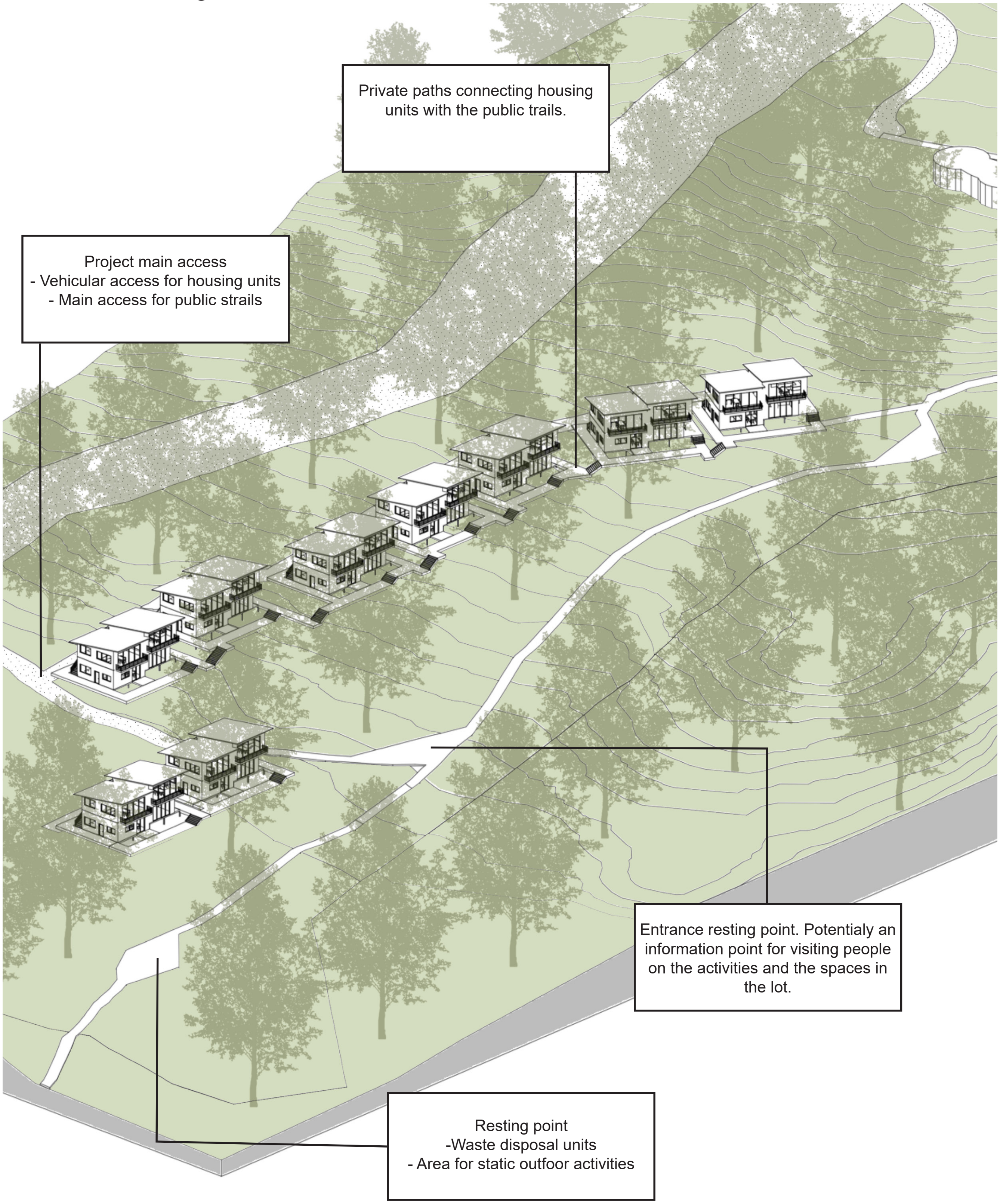


Existing paths/trails Potential Connections Proposal

There are different types of paths proposed inside the project. In the first instance, the private paths for the residents run along the southern façade of the house and connect with the public trail proposed in the southern area of the lot. Along the public trails, there are some specific points that serve as resting points during the hike but also have areas that can adapt for other activities such as: scenic viewpoints, given the rich natural environment inside the lot with its vegetation and fauna; picnic areas with recycling and waste disposal points to avoid contamination of the area and promote responsible waste disposal; fitness stations for activities like yoga or stretching exercises; and water stations. All of these activities are designed to promote the use of the trail, making it an attractive area for tourists and residents.

These resting points are located near the denser vegetation areas of the lot. The spot at the eastern end of the track is near the potential connection with Hunter Park and a stream that passes by in the surrounding lot. The second spot is connected to the main entrance of the project. This point works as a starting point for the trail in the lot and can serve as a meeting and information point for the users. The third point is located near the connection with the private paths and close to the second wetland of the lot. This point also serves as a sightseeing spot and resting point on the trail.

Trails and Resting Points



Conclusions

In order to conclude this project, it is important to provide a general overview of the different stages and how they led to the final proposal that could potentially answer our initial problem question: How can a multifamily housing design on Bowen Island, address the changing needs of a diverse age population while maintaining affordability and energy efficiency?. Also, it is crucial to understand how the proposal performed and what key insights can be taken from it to be applied to future projects.

Starting off with the theoretical framework, we took into consideration multiple concepts and understood how sustainability can be applied to housing proposals. To do this, we analyzed the use of different indicators and the reduction of environmental impact through energy efficiency strategies. Furthermore, we understood the concept of affordability in housing and what tools could be applied to achieve it. On the other hand, the project also considers other key concepts, such as energy performance and adaptive architecture, to respond to both environmental and social issues occurring on the island.

Moving on to the case studies taken into account, three main concepts made them an interesting reference for the project. First, in terms of affordability, two projects were considered, highlighting how sustainability principles and an emphasis on community aspects can create an affordable housing proposal. Also, the main population target of the project was interesting since it is partially similar to the one on Bowen Island.

For energy efficiency concepts applied to housing, two main projects were taken into account: a social housing project in the UK and a housing unit in the Netherlands. Both emphasize the energy performance strategies applied to the project. In the case of the Netherlands project, an interesting strategy arose, which was the use of local materials to reduce the carbon footprint of the building and create an affordable construction process. Finally, one project in Colombia was considered for the concept of palafitic architecture. This principle is used in the project to avoid any damage to the environment and promote efficiency in the housing unit.

Once the different concepts to be applied to the project proposal are understood, it is important to conduct a deep analysis of the project site on multiple scales. First, a municipality scale is analyzed, starting with the historical timeline. This is to understand how the island has evolved in terms of economic activities and habitability. From this historical timeline, it is important to highlight how environmental awareness and tourism have played an important role on the island. Historically, this island's main economic activity was the logging industry, although there are specific cases of other industries that have passed through the island. One of them is the dynamite industry, whose path passes through the proposal area and will be taken into consideration. Additionally, the natural beauty of the island has been a tourist attraction throughout the years and is a factor taken into consideration in the project.

The demographic situation of the island was also analyzed to gain a deeper understanding of the target population and their various characteristics. This analysis provides a clear image of their way of inhabiting space and their needs. Currently, Bowen Island's population is primarily based on family households. Historically, this island has been an attractive place for families to move to, but due to the high prices of housing units, it is not affordable for young adults or post-parental adults who want to downsize to buy or rent a house on the island. Currently, the better option is to move off the island. Knowing this, it is understandable that the problem lies in the lack of supply in Bowen Island's housing market in terms of small and affordable housing units that can meet the needs of these specific population groups.It is important to highlight the housing need report of Bowen Island, which underscores the necessity of creating sustainable houses through policies that promote the densification of housing units and provide flexibility in options for housing typology.

Moving forward, a territorial analysis was also performed to understand multiple elements of the island. Among these concepts, it was important to understand the island's stance in terms of the climate crisis and how they are applying different strategies to protect the natural environment. It was important to take this into consideration as the island promotes a sensible approach to housing unit development to maintain the multiple ecological corridors. Also, in the territorial analysis, concepts like transportation systems were taken into account. One important factor is the ferry services. Currently, the only access to the island is by ferry, making it crucial for the island's proper functioning.

In a deeper scale, it was important to understand how the specific site of the project is related on a territorial scale and its different dimensions. For this, the different lot characteristics in both regulation terms and environmental terms were examined. Here, elements such as the two wetlands and the development buffers are highlighted as they represent conditioning factors for any development of the lot. Among the main characteristics of the lot is that its access is through Adams Road, the main transportation artery of the island. Additionally, its sloped terrain towards the southwest creates an opportunity in terms of volume implantation. Another important factor that was taken into account for the proposal was the history of the lot and how this represented an opportunity to create activities within the lot. This lot was part of the old dynamite industry that existed on the island. Currently, one of its antique paths passes through the southern area of the lot. This, combined with the fact that one of the main recreational/touristic activities on the island is trekking and sight-seeing, presents a significant opportunity for the proposal.

Once all of these elements were taken into consideration, a proposal could be built to respond to all of the necessities. From the master plan scale, the project responds to the different constraints and limits based on the island's development policies and environmental factors. Additionally, looking to address both the housing supply deficit and population diversification, the proposal aimed to maximize the number of units in the lot without compromising important factors such as privacy or neglecting the natural environment around it. This is why nine multifamily housing units are proposed in the central area of the lot.

On the other hand, public space was also a key element in the proposal. As one of the main objectives of the project is to diversify the population, it is important to generate activities that attract people to the island. To do this, the antique dynamite factory path is proposed to be donated to the municipality as public space that connects to the current park and trail network existing on the island. In the lot, this path includes three resting points with an area sufficiently large to perform multiple outdoor activities such as yoga or sightseeing. These points, along with the path located throughout the southern area of the lot, aim to promote the use of the land by protecting the natural environment and avoiding any future developments that could endanger this essential aspect of the island.

In terms of the specific housing unit volume, it is composed of three apartments: one two-bedroom apartment on the lower level and two single-bedroom apartments on the upper levels. The volume is shaped in such a way that it responds to the slope of the terrain without compromising the interior space. For this, the volume is divided in half, and a one-meter elevation change is applied in the remaining volumes. Additionally, the palafitic architecture concept is applied to the volume, knowing that one of the island's main concerns is to preserve the natural environment. This strategy also helps in implementing energy performance measures such as airtightness and ventilation under the building. The volume is placed on the lot in such a way that the south facade has the main exposure. This passive strategy helps with energy performance by heating the space during the winter.

The inside areas were also intentionally distributed in such a way that the main social activities were located along the southern facade. During the housing typology analysis, there is an important space that was taken into consideration: the mudroom. This space can vary in dimensions and is often used as a back entrance to the house. The purpose of this space is to enter the household without making the inside dirty from outdoor snow or debris. In the lower level apartment, this concept is applied as a secondary entrance through the laundry room, giving the users the opportunity to get inside the house without passing through the main spaces. On the other hand, the upper level apartments both have a balcony facing towards the south, which also works as a shading device for the lower level apartment.

The different households projected inside the volume are proposed to respond to the demographic objective of diversifying the population of the island. This is achieved by implementing cost-efficient building strategies and energy performance strategies to ensure the affordability of the housing unit. The lower-level two-bedroom apartment is designed for the portion of the population looking to downsize from a family house, such as post-parental adults on the island. On the other hand, the two single-bedroom apartments are designed to accommodate the younger population and people who work on the island who seek a small housing unit just for themselves.

Moving forward, multiple energy efficiency and sustainable strategies were applied in the project. In terms of energy efficiency, these strategies ensured that the energy consumption of the building remained affordable for the user, taking the current housing supply on Bowen Island as a reference. Among these strategies are: southward orientation, overhangs as shading devices, high-performance insulation, airtightness, and renewable energy resources.

In terms of overhangs and shading devices, both levels include horizontal shading. On the lower level, the second-floor balconies serve as a shading device for the southern facade. On the upper level, the roof overhang acts as a shading device for the summer. The application of insulation ensured comfort in the interior of the house in terms of humidity and temperature. Airtightness was also an important factor for efficiency, as better airtightness makes it easier to maintain the inside temperature, making it more affordable for the users in the long run. The airtightness needs to be complemented with a Heat Recovery System (HRV) to ensure the airflow between the exterior and interior without compromising the inside temperature. Finally, double-glazed windows complemented the envelope strategies for improved energy performance.

Furthermore, other sustainable strategies were also applied to the project. Among these are water management, the raised foundation system, and the building materials. All of these strategies are meant to reduce the carbon footprint of the project. For instance, the use of local materials such as wood reduces the carbon footprint due to its availability and easy access for the project.

The energy performance of the project on Bowen Island has successfully met its goals by using advanced materials, innovative design strategies, and sustainable technologies. Through the incorporation of diverse strategies focused on energy efficiency and environmental sustainability, the project shows a notable improvement compared to traditional construction methods. The houses are projected to save a total energy consumption between 50% and 70% which will reach more energy saving than a conventional house, while accomplishing the environmental requirements.

One of the main contributing factors to this success is the building envelope, which is constructed with high-performance-material layers. Exterior walls, made of treated cedar wood cladding, rigid polyurethane foam insulation, and extra protective layers (wood fiber insulation, gypsum board), contribute up to 25% to decrease in heat transfer. By using this combination of materials, thermal resistance can be obtained with retaining the strength and moisture resistance of materials in the high humidity environment of Bowen Island. The roof, composed by mineral wool insulation and galvanized steel with a 20% slope for optimal snow and rain falls, reduces heat transfer by 20%. Furthermore, the elevated floors, insulated with mineral wool, reduce the heat loss through the base by 15% and shield the interior from the cold and damp ground conditions of the region.

Windows play a key role in the thermal performance of the envelope. With argon gas layers and low-E coatings, double-glazing leads to a 30% reduction of heat loss, minimizing energy transfer through cracks. The more extensive windows, set to the south, capitalize on passive solar gain in the north where possible, thereby utilizing as much of the sun's free thermal energy as is currently possible with a more direct heating solution in the winter, to provide a supplemental heat boost inside, while also reducing heating expenses by 20%. Collectively, these features create a balanced approach to maintaining indoor comfort while minimizing energy use. This reliance on clean energy significantly reduces the project's carbon footprint and dependence on non-renewable energy sources.

Beyond operational energy efficiency, the project emphasizes sustainability through the use of locally sourced materials such as treated cedar wood. In this strategy, it is possible to reduce both embodied energy and emissions from transportation, leading to a decrease in the project's global carbon footprint to 15% of its total growth.Including rain collection systems improves the sustainability of the design in the sense that it reduces the energy use for water supply and treatment by 10%. The shared wall layout of the homes increases thermal efficiency and reduces exposed surfaces and leading to a further 15% decrease in energy consumption for each block.

The project's success has also been manifested in the achievement of the 5 main energy efficiency indicators which, offer a quantifiable performance assessment. First, the Heating Degree Days (HDD) indicator highlights the project's capacity to address Bowen Island's annual HDD of approximately 3,800.High performance insulation, double glazed (argon gas filled) windows, as well as a south facing orientation that promotes passive solar heating all contribute to saving 30% during heating, thereby providing thermal comfort at the lowest energy cost.

The ODEX (Energy Efficiency Index) also confirms the effectiveness of the project's technologies in terms of technical energy efficiency.Through the incorporation of high performance building elements, such as rigid polyurethane foam insulation, and building technologies such as Heat Recovery Ventilation (HRV) systems, this project delivers a large reduction in total energy use, reducing it by 50% to 70% compared to conventional dwellings.

On Energy Consumption Per Unit of Area, the end results are reducing energy consumption from the average 150 kWh/m²/year in Bowen Island to only 45 kWh/m²/year. This 70% increase emphasizes the power of the combined approaches in decreasing energy use, at the same time maintaining acceptable level of indoor comfort.

The performance of the project is also good for Degree-Day Adjusted Energy Consumption, a key index to evaluate the performance associated with seasonal variations. Passive solar design, insulated elevated floors, and HRV systems allow it to achieve 30% reduction in adjusted energy use while delivering stable indoor environments and enhancing energy efficiency throughout the year.

Finally, the sustainability concern of the project related to CO2 emissions, were strategically avoided in an important quantity, which responds to an environmental value of energy savings. Through the implementation of renewable energy solutions, high performance startegies and the employment of local materials, the project avoids aproximately 4,437 kg of CO2 emissions per household annually, alligned to global efforts to reduce CO2 and environmental footprint.

In conclusion, the project has effectively met its energy performance goals by incorporating specific materials, sustainable technologies, and concrete design strategies. The integration of an optimal building envelope, renewable energy sources, and passive design principles leads to a symbolic reduction in energy consumption and environmental impact. This project surpass the energy efficiency standards, serving as a model for sustainable living that includes comfort and environmental responsibility.

Also, once the project was proposed, it is important to understand how the applied strategies worked towards economic performance, making the project affordable. To analyze this, the economic performance was measured by understanding the current market conditions in terms of housing supply. It became clear that there is a lack of supply in the market for single-person households or small households for post-parental adults. In the cases where these types of offers exist, the cost is simply too high for people to afford living there. This is one of the main reasons that there is low population diversity in terms of age on the island.

The project's economic performance was measured first through the understanding of construction costs, taking into account both labor and material costs. Knowing this, a preliminary total cost was set and taken as a reference for a potential sale cost. This cost, in comparison to the current market supply, is around 30% lower, making it affordable at the initial point of buying the house. Moving on to the economic performance in terms of energy consumption, a comparison was also made. This comparison made it clear that not only is the house affordable for purchase, but also the maintenance costs are low.

Finally, the social performance was also a crucial aspect to understand in the project performance. By analyzing this, it is understandable how the objective of population diversification and creating more activities is achieved. To do this, as mentioned earlier, the trails along the old dynamite tracks are meant to be for public use. These tracks are connected to the housing volumes and represent the chance to create interactions between residents and park users, all happening around nature.

Once the general overview of the project proposal is made, it is important to reflect on which points of the process could have been improved for a better result. One of the main obstacles along the way was coming up with a system that wouldn't be so intrusive to the natural habitat of the lot. For this, strategies such as the volume shaping and the palafitic architecture were applied. These specific strategies applied in the volume had a direct impact on the spatial distribution of the lower levels. For future reference, it would be interesting to explore other design tools to offer a better space for the house users.

In conclusion, an affordable housing unit proposal on Bowen Island should be applied in such a way that it responds to the current demographic challenges of the island and takes into consideration the environmental aspects of the island. Additionally, it is important to set new activities that could represent both economic advancements and demographic diversity within the island.

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