Buildings Integrated into Landscape & Making People Care for Them: Exploring Integrated Land-Building Ecosystems and the Lifestyles Needed to Support It

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Exploring Integrated Land-Building Ecosystems and the Lifestyles Needed to Support It.

A Thesis Presented

by

SARA MALLIO

Submitted to the Graduate School of the
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MAKING PEOPLE CARE FOR THEM

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Approved as to style and content by:

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Prof. Ray Mann, Chair

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DEDICATION

To Matt Mallio, without whom this would not have been possible.

ABSTRACT

**BUILDINGS INTEGRATED INTO LANDSCAPE &
MAKING PEOPLE CARE FOR THEM**

***EXPLORING INTEGRATED LAND-BUILDING ECOSYSTEMS
AND THE LIFESTYLES NEEDED TO SUPPORT IT.***

MAY 2022

SARA MALLIO, B.A., WELLESLEY COLLEGE,
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As climate change worsens, it is imperative that we make drastic changes to how our buildings are designed. We need to create building systems that work with and enhance the surrounding ecosystem. Many of these types of systems were developed and tested during the back to land and environmentalist movements of the 1970's. What is needed now is to synthesize these systems into packages that can be more easily adopted by the mainstream culture. By paying special attention to what people are willing to invest into their home's system maintenance and adapting the sustainable systems to meet those needs, we can craft truly sustainable and environmentally regenerative buildings and building systems to meet the needs of all people. Design strategies will be developed to engage the inhabitants with the building and its systems, prompting them to maintain those building systems with care instead of as drudgery. A 10-unit co-housing project will be designed with real clients to demonstrate the applicability of researched systems and design strategies. This thesis restricts its focus to systems applicable to residential building types, single family through multifamily, and to the New England climate.

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CHAPTER 1

OUR BROKEN PLACE IN THE ECOSYSTEM

Introduction

Climate change is the greatest global challenge of our time, and with buildings contributing up to 39% (IEA, 2019) of greenhouse gasses globally, the built environment is uniquely poised to be one greatest solutions to the problem. Indeed, we already have established building techniques and materials that can turn these mega polluting sources into carbon sinks, storing carbon that would have otherwise normally have been released and drawing carbon out of the air. This response has the powerful potential to reverse the problem buildings are currently contributing to, turning development from a problem into a solution (Racusin, 2019).

Many solutions and strategies already in use can make buildings greener, from drastically lowering operational energy, to using innovative (and not so innovative) materials to reduce or store carbon in construction. There is no one magical solution to this problem. Every building, site, and climate poses unique challenges, and encourages unique solutions.

In this thesis, I apply permaculture principles and ecological thinking to the design of both the buildings and the land. Here, the design process is used to develop sustainable and regenerative systems to support and provide for both the land and building needs in equal measure. In the end we all depend on the fruits of our land, so let us tackle this directly and discover how each building can coexist, with the management of the occupants, in a symbiotic relationship with the land upon which it rests. The thesis addresses this at the cohousing scale with a focus on the New England climate.

These are not necessarily new systems. People have been working toward a sustainable, community-driven environment since the 1960's and, further back, to indigenous cultures where working with the land was the only way to survive. These systems range from

whole building ecosystems, such as those developed for Bioshelters, Biosphere II, and Earthships, to sustainable agricultural farms, to indigenous agriculture systems, to DIY solutions developed by those working in intimate relationships with their unique climate. These systems include food, energy and fuel production, water harvesting, and on-site waste and water treatment with built-in resiliency in the face of increased weather events. Those systems that are integrated with the natural ecology, in balance with the land and natural ecosystems, are highlighted.

During the design phase of the thesis, I will integrate these approaches and strategies into a single test case, a co-housing project in Wayland, MA.

My two primary research questions therefore are as following:

What systems do we need in place to make buildings regeneratively integrated to the larger natural ecosystem?

How can we best design these systems such that people will implement and maintain them?

CHAPTER 2

HISTORY OF SUSTAINABLE SYSTEMS

Introduction

Sustainable systems, in both land and building, have two main origins: the indigenous peoples of the world, and the creative ingenuity of the back-to-landers in the 1970's.

Indigenous Agriculture Systems

The Kayapo, who live south of the Amazon river and along the Xingu river and its tributaries, build their homes within an inner circle, with their diverse farm spread out around them and the most useful plants of the forest pulled in close to feed them. Their specialized burn techniques produced soil that was rich in nutrients. Today, organic farmers strive to replicate this technique which they call "bio-char." The diversity of plants and the fertility of the soil in their circular farms made them resilient. Still, Kayapo didn't stop there: they reached out into the forest and shaped it by spreading useful cultivators, domesticating bees, insects, fish, birds, and other animals. Through their ongoing stewardship of the Amazon Forest, they lived in grew rich in food and biodiversity, increasing its overall resiliency. (Watson, 2020)

This type of forest farming is practiced by many other indigenous forest peoples across the world. The Milpa forest gardens of the Maya, and the Kihamba forest gardens of the Chagga in Tanzania. (Watson, 2020)

Even the indigenous peoples of what became New England regularly managed their forests and fields with fire to allow the cultivation in mounds of the famous "three

sisters," which is a planting of corn, beans, and squash where each plant offers a function that supports the others. (Native American Roots.net)

The En awenê-nawê, who live in Brazil near the Iquê river, took their forest farming into the river, building complex dams during the wet season to catch fish, then deconstructing those dams after two months and allowing the fish to swim freely to their spawning grounds. The building and quickly disassembling of these dams would mitigate much of the environmentally damaging problems that come with permanent dams. (Watson, 2020)

In India, the Bheri Wastewater Aquaculture lies at the edge of the city of Kolkata in West Bengal in the East Kolkata wetlands. Approximately 70% of Kolkata's wastewater runs through the wetlands which stretch across 12,000 hectares, of which 3,000 hectares are used for the treatment of sewage. This treatment started in the 1920's when some farmers decided to raise fish on the sewage. By the 1940's raising fish on sewage was a widespread practice. Today, these farmers are all part of cooperatives, of which only family member are allowed to join. Farmers shape the wetlands into a series of ponds, of which a sedimentation pretreatment pond is the first. Then fresh water is added, and it moves to aerobic, anaerobic, and facultative ponds until finally moving into the *bhari* ponds themselves, where the fish are grown. These ponds clean the sewage produced by Kolkata more effectively than modern mechanical sewage treatment plants. They do it while providing food for the citizens in the form of fish and plants such as rice and water hyacinth and a diverse ecosystem of about 50 fish species and 100 plant species. (Watson, 2020)

Complex cultural and spiritual practices accompany each of these practices, which integrate the practices into the fabric of the community's daily life. (Watson, 2020)

Biodiversity is key to healthy ecologies, soils, and environment. (Watson, 2020)

The Back-to-Land Movement

The United States can be considered to have had three back-to-land movements in the 20th century. Financial independence and self-sufficiency drove the first two waves of this movement, which grew out of economic calamities in the 1910's and the 1929 Great Depression. Food prices during these waves were relatively high: often 40% of a person's budget. Growing one's food was an excellent way to create economic independence. By the time the 1970s came around, food prices had dropped to 15%, and property values (along with the corresponding taxes) rose significantly. This made "living off the land" economically precarious when it was possible at all. As a result, many participants in the movement did so with nest eggs they could invest in the land. The 1970's wave was driven primarily by environmentalism, political dissatisfaction, and a rebellion against consumerism (Brown, 2011) and the nuclear family (Daloz, 2016) that was falling apart around them.

The back-to-land movement of the 1970's, which was the third wave of the movement, was a wellspring of creativity for developing environmental systems. This wave differed for the earlier waves in significant ways.

According to Brown, these "Back-to-Landers" dreamed big but failed to achieve many concrete accomplishments. However, this idea is belayed by the multitudes of sustainable building and agricultural systems rediscovered and invented during this time. While many of those discoveries lay dormant for decades, now they are being gradually refined by ardent fans. They are now emerging to drive the modern sustainability movement forward. (Brown, 2011)

The New Alchemy Institute was established on Cape Cod in 1969 to explore new and innovative environmentally sustainable systems. The Institute first experimented with translucent domes and created agricultural systems and planted forest "gardens" within these domes for fruit and nut production yields from the forest. (The term "forest garden" was later coined by Dave Jacke) Institute members created ocean ark boats and other

endeavors before moving on to make "bioshelters." These bioshelters were built on Cape Cod and Prince Edward Island as demonstrations. These bioshelters will be discussed further in the precedents section. (Todd, 1984)

John Todd was a driving member of the New Alchemy Institute. He was a highly educated man with degrees in agriculture, parasitology, and tropical medicine from McGill University, Montreal, and a doctorate in fisheries and ethology from the university of Michigan. He developed a waste treatment system that mimics wetlands. Called The Living Machine, it consists of six steps. The first step is an anaerobic reactor, similar to your traditional septic tank. Its purpose is to settle out the largest of the solids. Second, the effluent passes through an anoxic reactor and a closed aerobic reactor. Both have biofilters to control odors. The third step is an open aerobic reactor with vegetation growing over it instead of the biofilter. The fifth step is using a "settler" to settle the final solids. Finally, finally is the Ecological Fluidized beds which perform the final cleaning. (EPA, 2002) In many ways, this echoes the Bheri Wastewater Aquaculture systems, though more mechanized, as they both utilize the natural systems of wetlands. Other variations on this concept are currently in development.

Todd also wrote several books, including *Bioshelters and Ocean Arks*. In this book, he developed a list of Precepts of Biological Design. I found these precepts, while slightly different, echoed in many of the principles found in Permaculture, which was developed about the same time in Australia. Both systems focus on mimicking existing ecosystem designs. One precept, “Design Should Follow, Not Oppose Law of Life,” speaks to the role succession plays in nature and urges us to consider succession when designing. Ensuring designs which will be able to grow with changing population, or in our times case, changing climate. Under another precept, Design Should be Sustainable Through Integration of Living Systems, he describes a farm in Java which uses water flowing through to move nutrients through the farm, as water does in the natural ecosystem. This farm has the water entering and passing first under the animal shelters and out house to pick up nutrients, flow over a waterfall to aerate, flow through channels between raised beds to deposit nutrients from animals and irrigate, then to an aquaculture

and rice paddy before depositing their sediments in a pond to be periodically removed as compost/fertilizer. (Todd, 1984) Again, echoes to the Bheri Wasterwater system, as these sustainable systems use nature as a template.

Meanwhile, triggered by the energy crises in the 1970's, at the University of Illinois Small Homes Council, a group of engineers and architects worked on developing highly energy-efficient buildings by primarily focusing on the building's envelope. An article in 1986 Energy Review by William Shurcliff described these super-insulated building principles as:

a) thick insulation

b) airtight construction

c) prevention of moisture migration into cold regions within the walls, and other regions where much condensation could occur

d) optimum sizing of window areas

e) a steady supply of fresh air (Klingenberg)

This type of building was further developed at the time in Canada and later coined as *super-insulated* buildings by Wayne Schick. Unfortunately, as the energy crises eased, so did America's appetite for energy-efficient buildings. Also some of the first efforts resulted in mold and moisture problems before people realized how carefully moisture needed to be managed in these super tight buildings. Wolfgang Fiest in Germany took up the research and further developed it into the Passive House Certification as interest waned in America. In 2007, Katrin Klingenberg split from the German Passive House criteria, feeling that the single metrics for all climates, from Alaska to Florida, were too strict and impractical. She co-founded the US branch, PHIUS, Passive House US. (Klingenberg) Both the German Passive House and PHIUS keep to the original principles of the super-insulated house. These days, the moisture problems have been deeply researched and there are many varied building envelope solutions and ventilation systems that avoid the original moisture problems and allow the structure to breath and dry out.

CHAPTER 3

DESIGN FRAMEWORKS

Introduction

Sustainable systems design is assisted when using design frameworks to guide the process.

Permaculture

Permaculture was developed in Australia in the mid-1970s by Bill Mollison and David Holmgren, also inspired by indigenous methods, as an "integrated, evolving system of perennial or self-perpetuating plant and animal species useful to man." (Quotation from Bill Mollison and David Holmgren) It has since evolved into a way of conceptualizing nature's design of ecological systems into a design framework accessible to humans. David Holmgren has crystallized this framework through a set of 12 guiding principles. Applying these principles allows the designer to mimic the function of the surrounding ecosystems. Nature has evolved over the billions of years to maintain a balance conducive to the continuation and increase of life. Permaculture uses that evolved design of ecosystems to inform our design of our own systems. In this way, it is hoped that we can create balanced, self-sustaining, perhaps even self-replicating, systems which support humanity's current comfortable lifestyle and the richness of life around us upon which we all depend.

Some of the 12 Principles I find most useful are the following:
Catch and Store Energy, describing the importance of efficient use of energy, and the need to store for those cloudy days. (Holmgren, 2002)

Multifunctional Design, building for multiple uses. (Mollison) or example, a grape trellis in front of a southern window can produce food in the summer while blocking the hot sun and allow the winter sun in to provide some heat in the winter. Also, ducks are another popular example, producing meat and eggs, but also doing a good job at controlling the slug and other bug populations to keep the plants we grow for food safe.

Increasing the Edge within a System, (Mollison) as it is at the edges we most often find the most biodiversity and animal activity.

David Jacke and Eric Toensmeier helped push permaculture along when they came out with their books: *The Edible Forest Garden Vol I&II.* Jacke and Toensmeier focused on applying permaculture to forests and forest edges, developing guilds, or grouping perennial plants that worked well together, sharing similar soil and habitat needs or occupying complementary niches in the ecosystem. They also focused on vertically layering plants, with a guild consisting of short herbaceous plants low to the ground, bushes in the middle, and a tree filling in the top. The value of the second volume was its matrix with growing and edibility information for hundreds of edible perennials. (Jacke, 2005)

Currently, Permaculture is gaining popularity as sustainability moves mainstream. As it gains popularity, some people use it to push beyond sustainability and into regeneration. The idea is that we can use sustainability to do more than keep landscape ecosystems in their current state. We can increase their health, resiliency, and biodiversity when appropriate. (Reed, 2005) This idea reaches back to some indigenous practices that could increase the health of the landscape ecosystems through respectful management and stewardship.

Biophilic Design

Biophilic design seeks to provide people with an attachment to buildings and places primarily through design that mimics nature. According to Stephen Kellert: “without

positive benefits and associations, [to create] attachment to buildings and places, people rarely exercise responsibilities or stewardship to keep them in existence." We need to design in such a way that people care about what happens to the buildings they occupy and work to maintain them. Kellert lists numerous elements he believes are needed to create this attachment. (Heerwagen, 2008)

One of those elements is "Place-base Relationships, or Territorial Control." This element of biophilic design has many attributes, including creating connections to the place through geography, history, culture, and biology. It also recommends using indigenous materials and use the building to emphasize landscape features. In addition, it encourages the use of landscape ecology, to preserve ecological connectivity and resource flows. (Heerwagen, 2008) The site's design can be such that these elements are called out and highlighted, making people aware of the ecological web of life around them instead of hiding and suppressing that web. Only by celebrating that ecological web can we get people involved enough to nurture the ecological web that nurtures and sustains us all.

Another element of biophilic design is the "Evolved Human-Nature Relationship." Here Kellert lists the attributes needed in the evolved human-nature relationship which includes Prospect and Refuge, Order and Complexity (specifically in relation to structure, artistic detailing, or complex special relationships,) Curiosity and Enticement, Security and Protection, Affection and Attachment, Information and Cognition (which can be achieved though information screens showing system outputs), Reverence and Spirituality and others. (Heerwagen, 2008)

Biophilic design shows us ways to integrate nature into our design a way that helps increase people's attachment to their buildings. It is only through attachment that we can be assured that a building, and its associated sustainable systems, will be well-cared for in the future. This is key for the future of sustainable systems, for they are not maintained, they will quickly be abandoned and be replaced by our current more energy intensive and environmentally detrimental systems.

Pattern Language

Few summaries of architectural design frameworks can get away without mentioning Christopher Alexander's book *A Pattern Language*, and this thesis is no exception. In Alexander's seminal book, he lists hundreds of design patterns found in thriving towns, cities, and buildings, breaking out the elements that made these designs successful and describing them so others can take those elements to recreate successful building and urban plans. There were a handful of patterns that I found useful in my thesis, including:

#36) Degrees of Publicness: This pattern is to accommodate introverts and extroverts by building three types of houses: some close, many midways, and some far away, and three types of paths, wide paths, narrow paths, and twisty paths.

#37) House Cluster: It is recommended that it is best to cluster 8-10 homes together, open to open common land. The clusters should be kept separate but linked.

#9) Scattered Work: With this pattern, workplaces should be surrounded by family life. Decentralized workshops and offices should abound. (This is a pattern that COVID has helped to strengthen.)

#103) Small Parking Lots: Less than 9-percent of land area should be devoted to parking. The existing lots should be small, 4-6 spaces, and shielded with garden walls, shrubs, or trees.

#26) Life Cycle & #35) Household Mix: These two patterns speak to accommodating all stages of life in your community, so there is fee mixing amongst old, young, and middle-aged.

#61) Small Public Square: These should be a maximum of 60'-70' in diameter because it is only within 70' that one can recognize another's face and allow the square not to feel too empty if there are not many people occupying it.

#104) Site Repair: Place building on the worst and most degraded parts of the site, saving the best past for the enjoyment and for the landscape ecosystems to grow and be nurtured. Buildings do not need fertile soils. Farms do. (Alexander, 1977)

CHAPTER 4

PRECEDENTS OF SUSTAINABLE SYSTEM DESIGNS

Introduction

Following are the precedents I drew the most from as I created my own design.

BioShelters

BioShelter Arks came out of the New Alchemists Institute, which conducted environmental research and education from 1971-1991 on Cape Cod. The Prince Edward Island Ark (PEI), built in 1976 by Solsearch Architects, is one of the best known, though it has since been dismantled. The Cape Cod Ark, built in its current form in 1999, is still used to demonstrate the BioShelter Ark principles. These principles are similar to those of the EatrthShips. They revolve around the efficient recycling of waste and nutrients and the use of the sun's energy to fuel year-round plant growth. (Barnhart, 2008)

The Cape Cod Ark consists of a house attached to a 1800SF greenhouse. This greenhouse has a triple layer of glass and polycarbonate to allow the sun's heat to fully penetrate while having some modest insulating ability to keep the heat in once the sun goes down. Rainwater is captured off the roof and directed through fish tanks and then into the soil to water and feed the plants. The rainwater collects many nutrients vital to the plant's growth through the fishponds. Nine above-ground fish tanks totaling 6900 gallons of water provide thermal mass to soak in the sun's heat during the day and radiate in the back overnight. This large thermal mass, combined with the lesser thermal mass of stone walls, pavers, and the plants themselves, moderated the greenhouse's temperature and allowed the greenhouse to stay above 40F even during the coldest Cape Cod winter days. This temperature moderation, especially during the winter, allowed for food to

grow throughout the year. These crops included bananas and loquat, even in the temperate climate of Cape Cod. Being able to grow food year-round greatly increases the resilience and reduces the overall land needed to grow food for the inhabitants of a building. (Barnhart, 2008)

A recycling system keeps the nutrient wastes of the house occupants where it is needed most. A composting toilet separates the solid and liquid human waste. The solid waste is composted, and the liquid waste is sterilized and diluted before being used. (Barnhart, 2008)

Fig. 1 Cape Cod Ark, greenhouse

Fig. 2 Cape Cod Ark, exterior

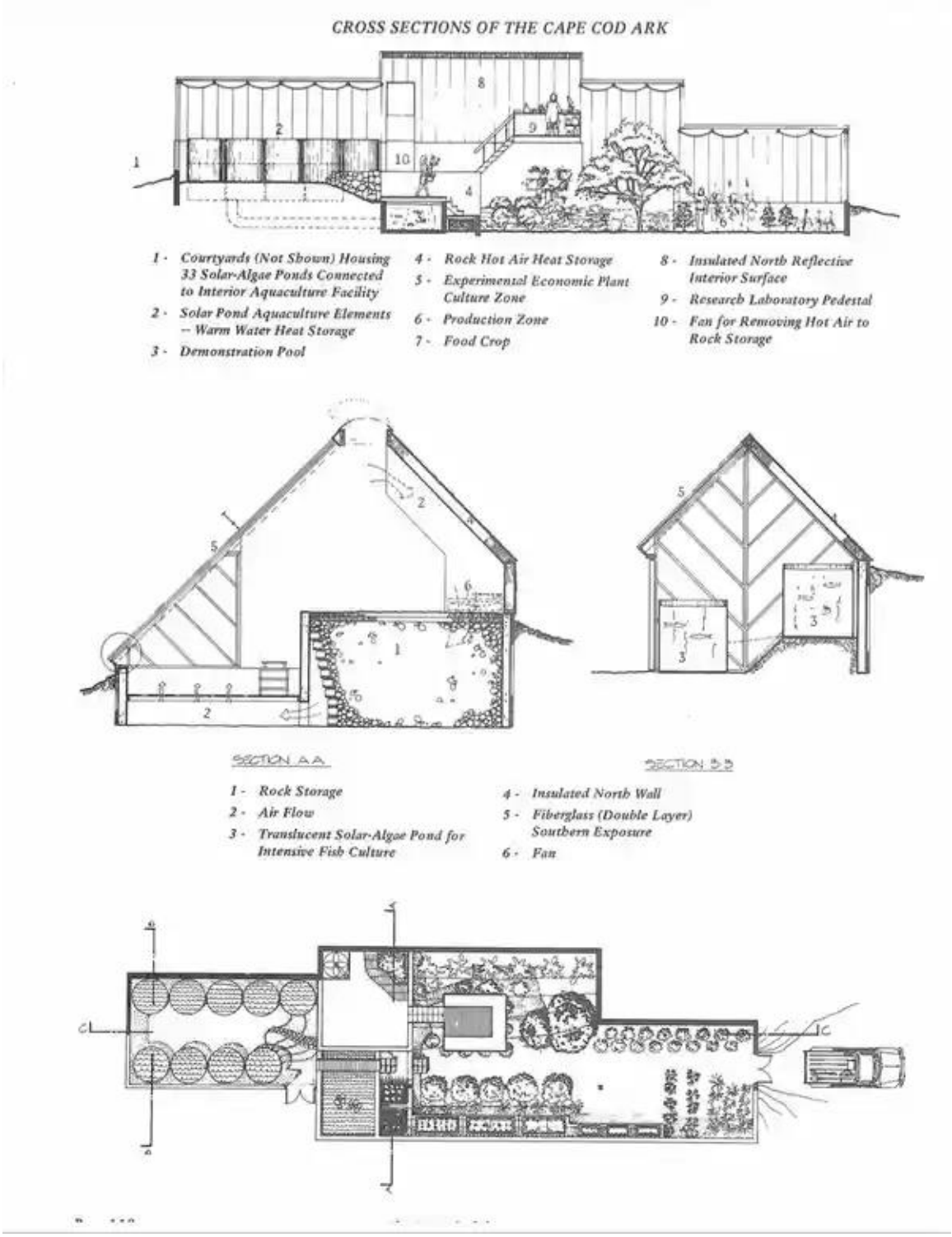


Fig. 3 Cape Cod Ark, Sections and Floor Plan (Rose, 2019)

Integral Urban House

At about the same time the Cape Cod Ark was being built, the Integral Urban House was being worked on in California by a couple, Helga and Bill Olkowski and the Faralloones Institute Staff. The Integral Urban House started with Helga and Bill questioning how they could enact the change needed to get to a more sustainable lifestyle. They identified nine factors which are involved in facilitating or impeding change:

1) Cultural or Personal Taboos
2) The Apparent Immediacy of Catastrophe
3) Amount of Sustained Awareness Generated
4) Family and Community Support
5) Amount of Stress Experienced from not Changing Behavior
6) Amount of information Available on Options for Change
7) Immediate Rewards Available (positive feedback loop)
8) Self-Image
9) Concrete Models Available

When these factors were identified in the 1970's, they were attempting to implement a recycling center. This is before recycling centers as we know them today, were even considered. (Olkowski, 1979) With climate change in its current state, we have found many of the above factors have changed. The Apparent Immediacy of Catastrophe is much more evident, as hurricanes and other violent storms increase, and sea levels rise. There are many Concrete Models Available, and there is more sustained awareness and community support, at least in some locals.

Helga and Bill expanded on these nine factors to develop a lifestyle change process. If we wish to slow down climate change and lessen the danger to our society, this process must involve:

-Problem Perception
-Goal Articulation
-Visualization
-Internalization
-Behavior Change Implemented
-Conclusion

In creating the Integral Urban House, the developers did a deep dive into systems thinking and looked at different types of systems, particularly as they pertain to ecosystems. They found that a "closed integral loop is fundamental to the nature of living systems," and that ecosystems are webbing with "multiple channels and loops." (Olkowski, 1979) Ecosystem energy distribution happens in stages, and in small increments, with too much energy short-circuiting the system (floods.) (Olkowski, 1979). One can see the consequences of that overflow of energy in our society, short-circuiting negative feedback loops, allowing harmful activities to continue without immediate consequences. All of this echoes the permaculture ethos of multifunctional and resilience. It also underscores a fundamental element to life, connections. It is the connections, multi-faceted and redundant that makes life possible. Any sustainable system will need this web of connections, and that web will need to spread from land to building and back, for, in the end, all life depends on nature.

Fig. 1 shows the Energy Flow in a Closed System Habitat (Olkowski, 1979). The inner ring is the functions humans depend on to live: temperature regulation, food preparation (cooking), safe disposal of excrement, water for drinking and cleaning, shelter from storms, and energy for all of our modern comforts. The second ring provides these needs, the technological wonders we have devised to turn raw materials into the functions and

things we need. Finally, the outer ring is those raw materials, sun, soil, water, and wind, the four elements.

The Integral Urban House systems used were not much different than the Cape Cod Ark. Because of the urban space constraints, the greenhouse was much smaller and less elaborate. Aquaculture was therefore moved outside. A composting toilet was used with the kitchen waste placed to be dropped right from the kitchen counter into the composting toilet. Chickens and rabbits lived by the compost on the north side. Grey water was utilized, though they cautioned to watch what was put into the grey water system, as high chemical waste products can cause chemical build-ups in the soil.

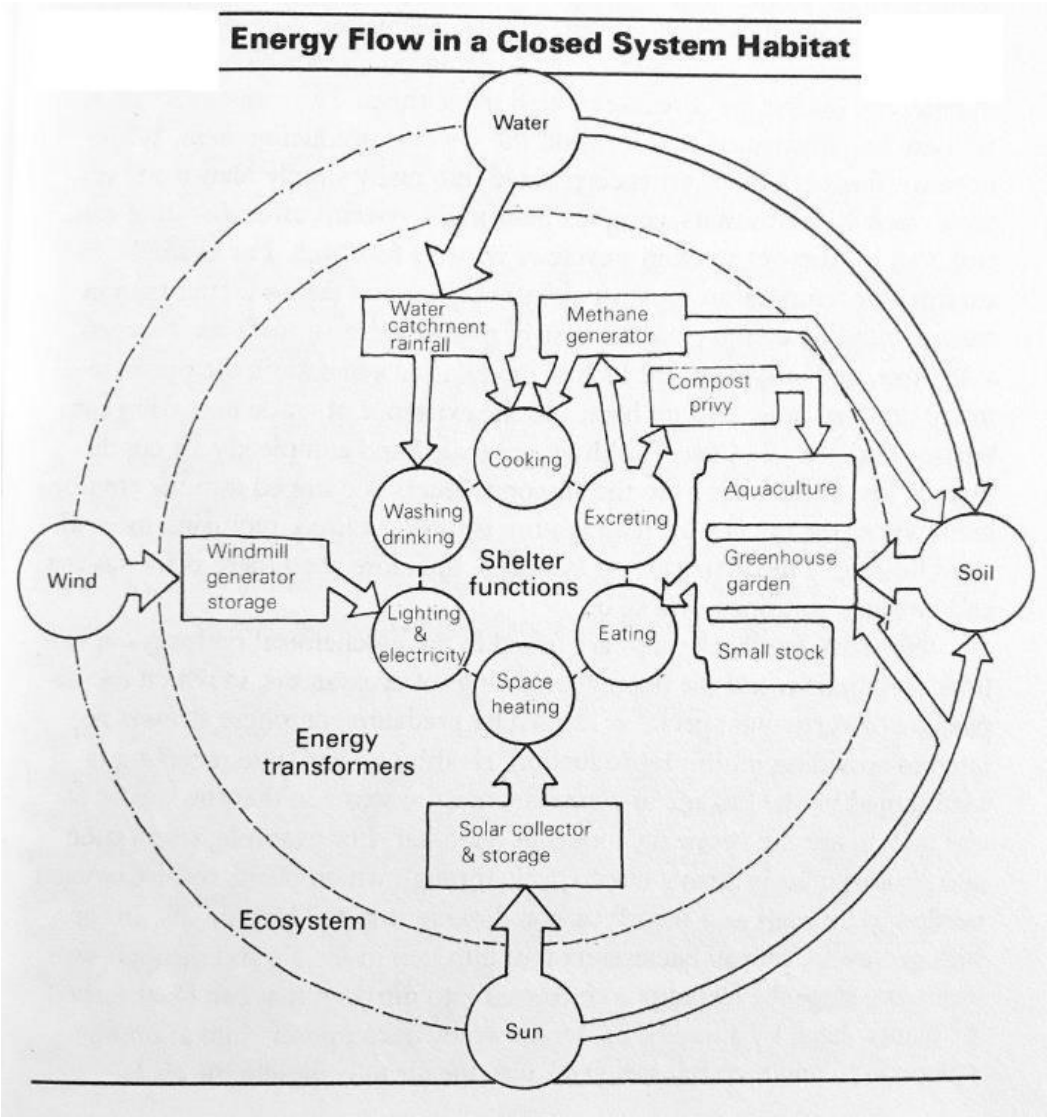


Fig. 4 Energy Flow in a Closed System Habitat (Olkowski, 1979)

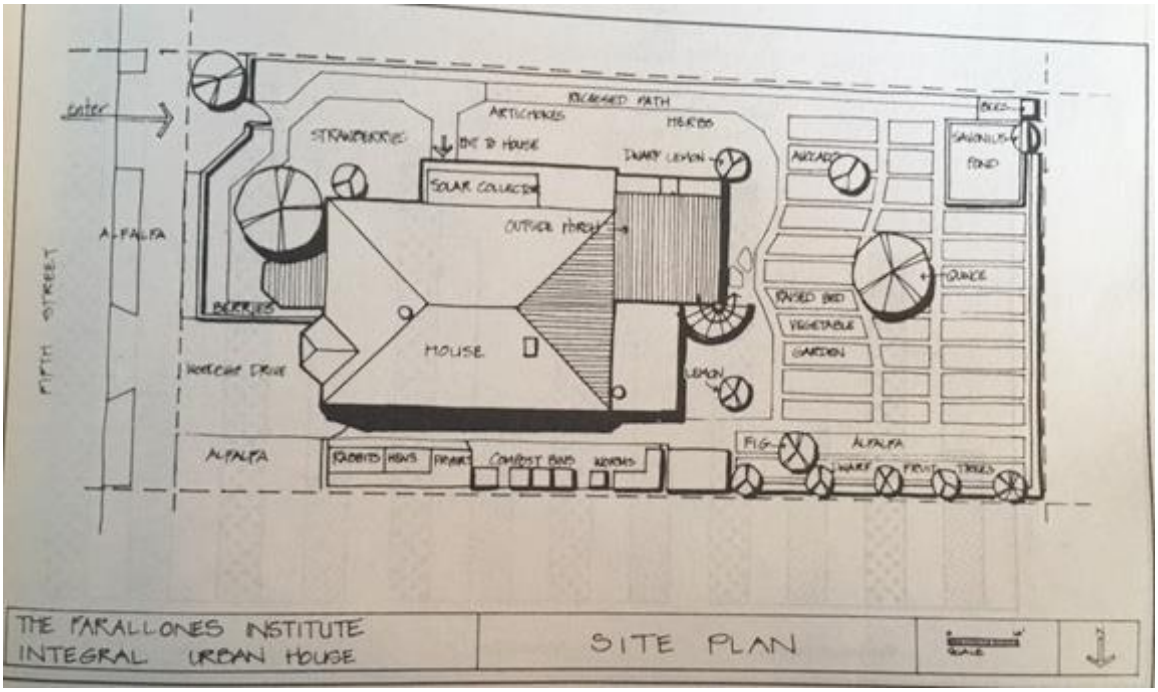


Fig. 5 Integral Urban House Site Plan (Olkowski, 1979)

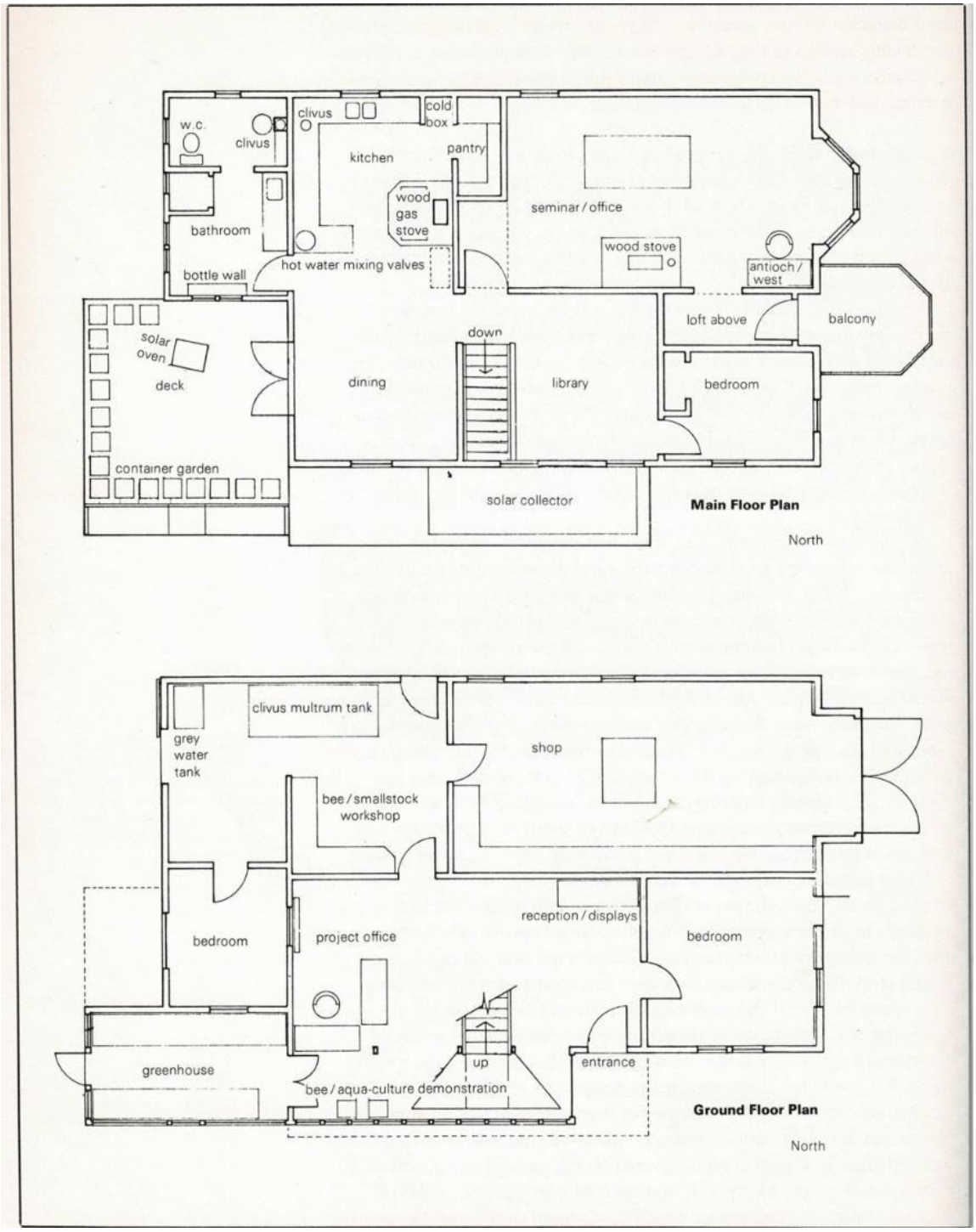


Fig 6 Integral Urban House Floor Plans (Olkowski, 1979)

Village Homes

Fig. 7 Village Homes (Dingemans, 2018)

Village Homes is a development built between 1975-1983. It is 70 acres with 245 units split between single family homes and small apartments. Each home built was individually designed, but had to adhere to certain sustainable principles, the biggest being solar systems. The village center consists of not just a community center, but also a business center, where residents can have a store, restaurant or office. Agriculture was mixed in as well as shared open spaces for community recreation. Paths wound through the backyards, to encourage walking, biking, and serendipitous interactions between the paths and backyards. Spaces for acrs was minimized. All these elements have created a very successful community whose homes are still in much demand today. (Dingemans, 2018)

CHAPTER 5

STRATEGIES FOR CREATING SUSTAINABLE WHOLE SYSTEMS

Water Systems

Water is necessary for life: it flows and lubricates life functions of life and allows movement of energy and nutrients through the living world. Because of water's central role as the lubricant of life, it plays multiple roles in human lives. We use it for irrigation. We use it to water our animals and pets. We use it to clean our clothes, our cars, our dishes, our floors, our buildings, ourselves. We use it to flush our toilets, lubricating the disposal of our bodily waste. And we use it to cook in and drink. Each of these uses require a different level of cleanliness. Purifying water such that it is suitable for drinking, requires intensive energy and resources. Therefore, some water systems split water into two tracks: grey water and black water. Grey water is used for washing, dishwashers, sinks, washing machines, and showers, so that the purified and energy intense drinking water is conserved for just drinking and cooking. Black water is toilet water, water contaminated with excrement. Grey water can be reused for toilet water and for irrigation. Most articles advise to apply grey irrigation water underground when irrigating plant for consumption to avoid possible contamination. How likely contamination is through the application of grey irrigation water is an area that still needs further study. For the most part the risk seems low, though not zero. (Busgang, 2015)

WATER RETENTION

One of the most known water retention systems is the collection of rainwater from roofs. This water is classified as grey water and can be used in any function that does not require potable water, or it can be filtered and disinfected and used as potable water.

Retention systems also include swales and keyline farming. Swales are created on sloping land perpendicular to the flow of water. A depression is dug in on the uphill side, and a small berm is constructed on the down hillside with the earth from the dug depression. As the water runs down the land, it hits the berm and is held at the depression. This allows time for the stormwater to infiltrate the soil. As a sufficiently large storm can overrun a swale system, they should be designed to take large storms into account. This includes extra retention areas and infiltration spots for large storms. These should be designed to handle 5, 10, and 20 years storms with no assistance. Only in the case of 50 or 100-year storms might the additional retention areas come into play.

Keyline farming was developed by P.A. Yeoman. The basic idea behind this is to plow such that your plow lines form mini swales, reducing runoff and erosion. The creation of artificial streams, ponds, and retention pools are also a part of this system. Its goal of is to slow stormwater down as much as possible so it can infiltrate, be available for times when rainstorms are not occurring, and feed the local plants. These strategies can also be used on the regional scale to help provide water and wastewater treatment to cities. (Yeoman, 1993)

Water is a critically important part of any system to move nutrients and energy through the system. Wetlands are a critical component of water retention and water treatment. They are nature's water purifiers. And as was mentioned earlier in this thesis, they are used as a template for natural water treatment systems.

Waste Systems

Waste can be divided into two categories: liquid waste and solid waste. Liquid waste can be further divided into grey water or black water (sewage, as described in the previous section). Solid waste can be further divided into compostable waste, recyclable waste, and that which can be neither composted, nor recycled.

The types of waste systems in use are many and varied.

LIQUID WASTE SYSTEMS INCLUDE:

- Septic Systems
- Municipal sewer systems
- Smart Sewer systems
    - Takes in sewage and compost from restaurants, farms and/or residences; producer: grey water for irrigation, and gas (methane) from the biodigesters which can then be burned to produce electricity. These systems are net producers of electricity.
- Microbial Fuel Cells (citation)
    - Used in small residential situations.
    - Produces electricity through the microbial work of biodigesters.
    - Researchers are still working out how to scale them up for municipal use.
    - Used with a septic tank and disinfecting stage, can produce potable water.
- *Bheri* wastewater aquiculture system in Bengalese, India (Watson, 2020)
    - Uses lagoons, retention ponds and subsequent fish ponds to combine a commercial fishing enterprise with waste water processing.
- The Living Machine (EPA, 2002)
    - Recreates the functions of a wetland in a series of tanks.
    - Some of the tanks used are open at the top and planted with plants in a hydroponic manner.
    - Must be in a greenhouse or indoors in cold climates to keep the water above freezing and flowing.
- Wetlands
    - Several municipalities are using wetlands as a key, integral part of their wastewater treatment.

SOLID WASTE SYSTEMS INCLUDE:

- Composting
    - Composting produces both nutrient rich soil for heathier, stronger, and larger plants as well as by product which can be used for energy generation.

    - Aerobic: This can be used as a heat source as the bacterial breakdown of compost in the present of oxygen produces heat, with the temperature of compost piles regularly reaching temperatures of 120-160F, and in extreme cases catching on fire. One way to use this as a heat source in a small residential application, is to run water pipes through a compost pile and use that heated water in a low temp hydronic heating system. Could also be used to heat domestic hot water.
    - Anaerobic: This method needs to take place in a warm environment, which is why it is most often used in tropical locations, although it can also be successfully done in cold climates if kept warm. It produces gases, notably methane, as a primary component of the bacterial reaction, which can be captured and burned for heat or electricity.
- Recycling:
    - Cottage plastic recycling through 3D printing: some people melt down their household plastics and use them in their 3D printers to create new plastic items. I would think that the type of plastic used would make a big difference in the viability of this, but I am excited by its potential to create a cottage industry of neighborhood plastic recyclers making new items on their 3D printers.
    - Neighborhood recycling of items that can be used again by others or repaired and used again. Examples: Repair Café, Local swap shops...
- All other waste: usually incinerated or put in landfills.
    - Trashology: a company which is/has developed an onsite and mobile trash-to-energy process which involves incineration of trash to produce a synthetic gas which can be used as a natural gas substitute to provide electricity or heat to the building.

Energy Systems

As mentioned in pervious sections, energy systems can often be integrated with waste systems, as the waste processing can generate heat or gas which can be used to generate energy.

SOLAR:

- Photovoltaic panels
- Water heating panels
- Solar heat gain (buildings and greenhouses esp.)
    - Use of trombe walls and mass storage in these situations.

WIND

- Turbine
- Bladeless (https://vortexbladeless.com/)
    - This has potential for applications where height and space and zoning limitations make typical bladed turbines not doable. Guessing energy output is likely lower, but could work well in combination with other sources like photovoltaic panels.

HYDRO/WATER

GEOTHERMAL

HUMAN/ANIMAL

- Bikes/exercise equipment to generate electricity. Example: https://www.nationalgeographic.com/science/article/151006-energy-drink-billionaire-wants-to-power-homes-with-bikes This would obviously only be supplemental, or for use in places with extremely low energy demands and no grid connection.
- Bacteria generate a great deal of energy as they break down our trash and waste. A number of ways have been developed to capture this energy, from indirect methods (heat and gas capture) to direct methods (Microbial Fuel Cells) and are often integrated into waste treatment systems.

STORAGE: Storage is a critical component of renewable energy generation. Most renewable energy generation happens only under certain conditions and is intermittent, while our energy demands are constant (with day/night cycling).

- Batteries
- Flywheels
- Water – through heat storage or pumping to high elevation ponds, then recapturing the energy through hydro dams.
- Mass/thermal storage

CONSERVATION

- Thermally efficient building envelope
- Energy efficient appliances

CHAPTER 6

A SUSTAINABLE CO-HOUSING DEVELOPMENT

Introduction

For my project I have chosen to design a sustainable permaculture development in Wayland, MA. It is located on an 8 acre south sloping wooded lot at the end of a cul-de-sac and surrounded on two side by trailed conservation land. There is an existing house on the site built in the 1970's. While structurally in good condition, the house's HVAC system and thermal envelope needs a complete overhaul. I have been blessed to find to real life clients one of which currently lives on the proposed site, while the other grew up there. They have been working on the idea for a few years now of creating a sustainable, permaculture community that would demonstrate a different way of living from the typical isolated suburban bedroom neighborhood. How can people live together in a truly sustainable community?

The clients have taken two models as their inspiration, the first is to be rooted in permaculture methods of agriculture as a basis for the sustainable systems of the new development. The second (which emerged later in the process) is the European town square, which they admired for its ability to encourage and engage community while coexisting with automobiles. While I had long felt permaculture was a key design strategy for sustainable systems, I had never considered the European town square for community engagement. But once they explained the concept to me, I was caught and intrigued by the idea. By using a town square as the model, this permaculture development, tucked at the end of a suburban neighborhood, and surrounded by woods, would have the density of an urban center, instead of the usual one acre single family lots that were the standard called for in the town's zoning by-laws. I knew, by whispers through my network, that there were a few permaculture developments in New England, so I did a quick google search to find them, and came up with only a very few, and all of

them consisting of single-family homes. I knew then that the clients were on to something. For there is no question that concentrating the buildings in a small space while leaving the majority of the land available for growing agriculture, animals, and the wild things of nature is the most sustainable avenue.

The community will be diverse, with a range of ages and incomes. To that end the size of the units will range from 1 to 4 bedroom units. In addition, they wanted work to be more integrated into the community. While they know that some of the residents will still be tied to an office building job, they are hoping that some of the residents will be able to work within the community. Whether that will be through artist, makers, or business owners who can work out of their home or remotely will not be known until the residents are found. In the end it is felt that work and production must be integrated to some extent in order for the community to be successful.

Another critical component of this project for the clients is that it will be a model community for others. To that end they envision extensive engagement with the wider community. They want to show how people can interact with nature in a regenerative way, and that doing so does not mean making sacrifices, and that in fact it can be the means to a richer and deeper life.

To summarize the goals of this project:

- Preserve the land
- Service to and engagement with the broader community
- Demonstrate a new way of living
- Sustainable living, regenerative
- Integration of livelihood into community.
- Experiment how to live more in the community through design
- Show how people can interact with nature in a regenerative way
- Use older techniques
- Diversity of: age and class
    - 50% of units will be affordable

Fig. 8 Site Analysis

Fig. 9 Existing House

Fig. 10 Existing Barn

Fig. 11 Existing site panorama of south facing slope

Programming

For reasons of zoning, 10 units was chosen. The distribution of those units are as follows:

- (2) 1 bed
- (2) 2 bed
- (4) 3 bed
- (2) 4 bed

Each of these units will have a full bath, mud room (or mud area), open kitchen living and dining room, condensing washer/dryer unit and the noted number of bedrooms with closets. Larger units will have an additional half bath on the living floor. Storage will be minimal as there will be communal storage available in the basements. The dining and living rooms of each unit will have views and connection to the Town Square communal gathering space. Each unit will also have some outdoor private space where they can sit and decorate/garden as they please. The one bedroom units will be accessible, to further the inclusive and diverse vision of the community. I primarily see this unit as an aging in place unit, but would of course also be available to disabled individuals.

The focal point of the community space will be the town square. This open space between the residential units and community building needed to be carefully designed to encourage community interaction. It will be hardscaped with permeable pavers to allow for cars to come close to the units for groceries, and accommodate a fire truck turning radius, while welcoming kids playing soccer and neighbors chatting, or hosting a party. Permaculture gardens will be integrated along the edges with the hardscape to allow separation, permeability and a variety of spaces between the private units and the public square. The greenery will also soften the hardscape and remind residents and visitors of the surrounding nature they are stewarding. Porches or sitting areas at the residential units will give the residents a space they can be slightly apart from the community space, while still being able to readily join in if they choose. A cob oven will be adjacent to the town square for outdoor community cooking.

Other outdoor spaces will include the agricultural fields, silvapasture areas for the animals, and the woods. The woods will be slowly managed to grow mushrooms, nut and fruit trees as desired by the residents, and produce wood for fires and lumber. All will be done in such a way so as to keep the ecosystems healthy, and work in harmony with the local wildlife. A harvesting room/area will be created for the agricultural harvests to be cleaned and processed. It will also need a distribution area for residents to pick up their food. A root cellar will store appropriate harvested foods.

There shall be 2-3 sacred spaces on the property for residents. These shall be quiet, contemplative places. One will be near the rock ledge over looking the community buildings. The other(s) will be deeper in the woods.

A barn will be located not too close to the residential units, but also close to the community building and agricultural fields. It is important that it be close to the harvest processing area, kitchen and food storage for ease of movement of the food products (and manure) the animals will produce. There was also a desire to make it easily accessible to the children, as there is little more wonderful for children then time spent with animals. The barn will shelter chickens, goats, and horses depending on the desires of the community. There will be a paddock attached to the barn and the composting will be adjacent to the barn for ease of manure transport.

A farmstand and store, located in the community building, will be built to facilitate the exchange of goods and ideas between the wider community and the residents. Parking shall be provided along the periphery of the town square as unobtrusive as possible.

The indoor community spaces will be housed in the community building. The heart of this building will be the dining room and greenhouse. The dining room will be large enough to hold all the residents, and possibly larger to allow for some guests. It can also be imagined that public events will be hosted here to show case the success of this model community. The dining room will open out onto the greenhouse which will allow for some dining within its green spaces. The greenhouse will need to be connected to the harvesting space as this will be a working greenhouse where much food will be produced

in the winter months. Adjacent to the dining room will be the kitchen. This will be a commercial kitchen to allow for the residents to turn the fruits of the land into salable products for income, supporting the goal of integrating work within the community. The use of this kitchen will depend on the needs of the community. The kitchen will also need to have a food storage space adjacent and be connected to the harvesting space as much of the food harvested will be moving through the kitchen. The design of these spaces shall allow for the hosting of public events should the residents chose to do so to share the experiences of their community.

There will also be a workshop. This space will primarily be a woodworking shop, but it should have the flexibility to house any type of shop activity as the resident's passions arise, such as a makerspace with 3D printer and/or welding area. A library will be acoustical removed from the workshop. This space will give the residents and guest a quiet place to retreat to and can also function as a co-working space. Two office rooms will be adjacent to the library. These office rooms can be reserved by residents as the choose, and will also contain murphy beds, allowing them to be converted into guests rooms to house resident's guests. A bathroom with a shower will be needed to support this guest room function. There will also be a laundry room with a large capacity washer and dryer so residents can wash large comforters and bedding that may be too big for their smaller in unit washers.

The children's play room will be located under two of the residential units and open out into the atrium. This places the children in the heart of the residential units, and allows them to use the atrium as an extended play area if desired.

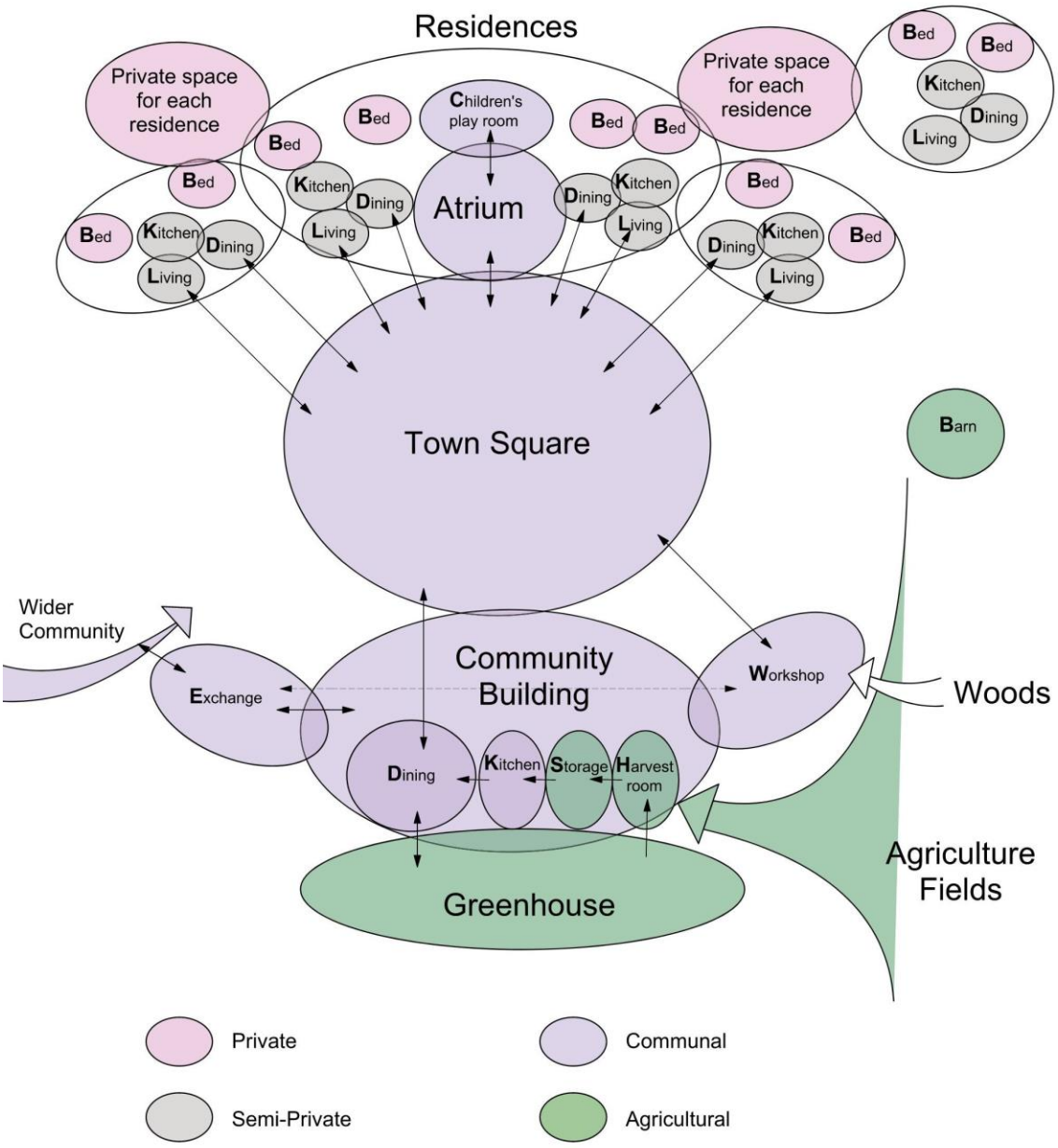


Fig. 12 Programatic Bubble Diagram

Design

For the design process, I started with a systems decision matrix (Tables 1&2). These laid out the pros and cons of each available system in different categories. They were to assist in choosing the most appropriate system for each individual client. Unfortunately I was unable to complete all of them. The next thing I did was to sketch out a diagram of the systems with the programming scope in mind. (Fig 13)

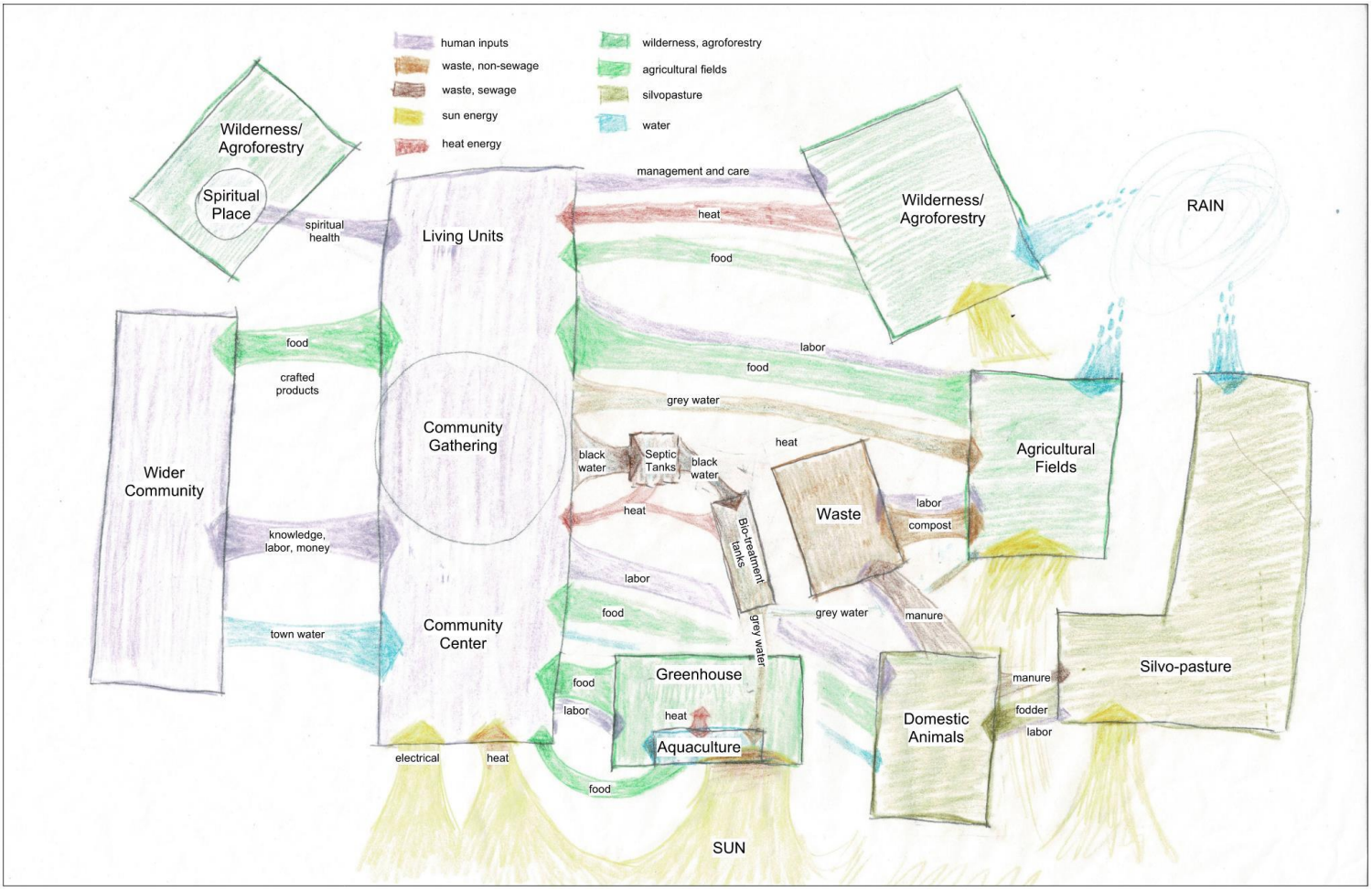


Fig. 13 Systems diagram

RESIDENTIAL SYSTEMS decision matrix

esitmates based on 4 bed, 2,000SF high performance house

rankings from 1-5, 5 being highest satisfaction, or good) PROS CONS

	Criteria Data		Costs: Initial $ Cost	Costs: Operational cost $/ Materials	Costs: yearly Maintance cost	labor/time	Enviromental effects	Yields	Other	SUSTAINABILITY VALUES: Energy Efficiency	Carbon Footprint	Health/Non-Toxic Materials	Climate Resilience	Social Justice
HVAC	Gas/Oil Boiler/ Furnace		$2-10k	Fuel purchase $1k-2/year	yearly cleaning	none	CO2 and particulate emmissions	none						
HVAC	Heat Pump		$2-10k	addt'l electrical costs: $750/year**	yearly cleaning of filter	none	varies based on electrical source	none	highly efficient electrical use					
HVAC	Jean Pain Compost Heater		$500?	$0 (unless material is purchased)		yearly creation of pile	none	compost	exsercise					
HVAC	Wood fired furnace/boiler		$2-10k	1-2 cords, $0-800	$30 for new cord gasgets every few years	20mins/heating day, plus wood chopping/cutting if not buying	CO2 and particulate emmissions	ash for garden, can also make bio char	exsercise, outdoor time for improved mental health					
HVAC	Wood Stove/ Masonry Stove		$2-3k wd stove, 10-20k msnry stove	1-2 cords, $0-800	$30 for new cord gasgets every few years	20mins/heating day, plus wood chopping/cutting if not buying	CO2 and particulate emmissions	ash for garden, can also make bio char	exsercise, outdoor time for improved mental health					
HVAC	Electric Resistance Heater			addt'l electrical costs: $1.5k/year*	minimal		varies based on electrical source	high						
HVAC	Passive Heating/ Cooling	Thermal efficiency	integrated into house design, 5-10% addt'l	none	none	none	none	none	increased thermal comfort					
HVAC	Passive Heating/ Cooling	Air barrier	requires addt'l ventilation unit $500-3k	addt'l electrical costs: $?/year	yearly cleaning of filter	none	varies based on electrical source	none	healthier air, fewer particulates/ pollutants					

*based on 10,500 kWh @ $0.15/kWh (kWh hour taken from high performance 1700SF house in northern VT (Mottram, 2021))

**based on energy.gov estimate of heat pumps as 50% more efficient than electric resistance (DOE)

Table 1.

RESIDENTIAL SYSTEMS decision matrix

rankings from 1-5, 5 being highest satisfaction, or good) PROS CONS

	Criteria Data	Costs: Initial $ Cost	Costs: Operational cost $/ Materials	Costs: yearly Maintance cost	labor/time	Enviromental effects	Yields	Other	SUSTAINABILITY VALUES: Energy Efficiency	Carbon Footprint	Health/Non-Toxic Materials	Climate Resilience	Social Justice
WASTE	Municiple Sewer System	none if already connected	$14-$135/ month	none	none	some - depends on municiplaity	none						
WASTE	Septic System - traditional	$10-60k+	none	$250-500 every 2-3 years, for pumping	none	minimal	none						
WASTE	Septic System - bio cells	$1,500-$12,000	$3-$5/ month electrical	replace purification unit	minimal	minimal	electricity, minimal						
WASTE	Composting Toilet	$1k-4k/ dwelling unit	none	none	-every 2nd day, rotate drum(?) empty drum 2x per year or more	Puts human nuetrients back	Compost	Excersise					
WASTE	Living Machine	? high	minimal	?	upkeep of plants and pools, 1-2hrs/week	recycles water & nuetrients	veggitables, fish, nuetrient rich water, potable water, heat sinks	beauty of ponds and gardens irrigated					
WASTE	Smart Sewer (for multi family only)	? High	minimal	?	?	Minimal	electricity, nutrient rich water, heat						

https://www.movebuddha.com/blog/average-utilities-cost-guide/

Table 2.

I knew from the start that I wanted the residential units to be dug into the south-facing slope to best catch the solar heat and to utilize the steeply sloping land that was unusable for agricultural purposes. The community building would land opposite the residential buildings with the town square between in the existing flat space at the bottom of the slope, with the greenhouse on the southern side of the community building.

Starting with the agricultural systems, I looked for appropriate locations for the agricultural fields, silvopastures, and woods. My primary criteria was slope, with the flattest areas going to agricultural fields, the middling slopes to silvopasture, and the steepest to woods. I also looked at proximity to the barn and harvesting area for the silvopasture and agricultural fields, as we didn't want those too far away. Sun is a big consideration but can be augmented with selective tree felling if necessary.

With the water systems, I first determined that the project would be using town water for its potable water source. Then I looked at storm water run off and irrigation. I knew that with the residential units dug into the side of the hill, water running down the hill would be an issue. I used grade changes to direct the water away and into small streams that will bring the water into a small pond in the center of the town square and from there into another pond and overflow area near the agricultural fields. Having these little storm runoff streams run through the residences will connect the residents more closely to the flow and dispersion of water on their land. Making them more aware of the availability and importance of the water they use.

The waste systems would be closely integrated with the water system, since water moves the nutrients in nature, so I looked at waste next. At first I wanted to install a Living Machine waste processing system because I felt that would give people the greatest connection to the waste processing in a pleasing manner. But as I got deeper into the design, it got bigger and more complicated, until I finally felt it was beginning to feel forced. As much as I wanted to have the visibility of the Living Machine systems, in the end I concluded that the project was not quite big enough for a Living Machine system so I moved to a more conventional septic system. In an effort to keep as much awareness as possible, and to keep the leaching fields as small as possible, I designed a split grey and

black water system. The grey water will flow into the irrigation pond near the agricultural fields and will flow through the aquaculture tanks in the greenhouse. The lower pond can be used to irrigate the agricultural fields in times of drought. The grey water will also be used in the greenhouses, especially in the winter when flow outdoors will be difficult. All organic wastes will be composted, with that compost going to the agricultural fields. This includes kitchen wastes and manure. Clean kitchen waste may be fed to the chickens.

The buildings will all have a robust thermal envelope and tight air sealing. The structure will be timber frame, using the large white pines currently growing on the property, with strawbale walls covered in with a rainscreen and single siding for a low carbon construction. Deep overhangs will further protect the strawbale from moisture. Airtightness will be to ACH .5 with an HRV system for ventilation.

Heat will also be passively provided by solar gain through the southern windows. The windows and overhangs are designed to allow the winter sun in while blocking the hot summer sun. Active heat will be provided by a geothermal system. The tubing for this geothermal system will lie with the septic system leach field. This will allow for one excavation instead of two, and will allow the geothermal system to pick up the latent heat from the black water moving through the leach field. For energy, the project will be tied to the grid with net zero consumption. PV panels on the roofs will provide the electrical energy needed.

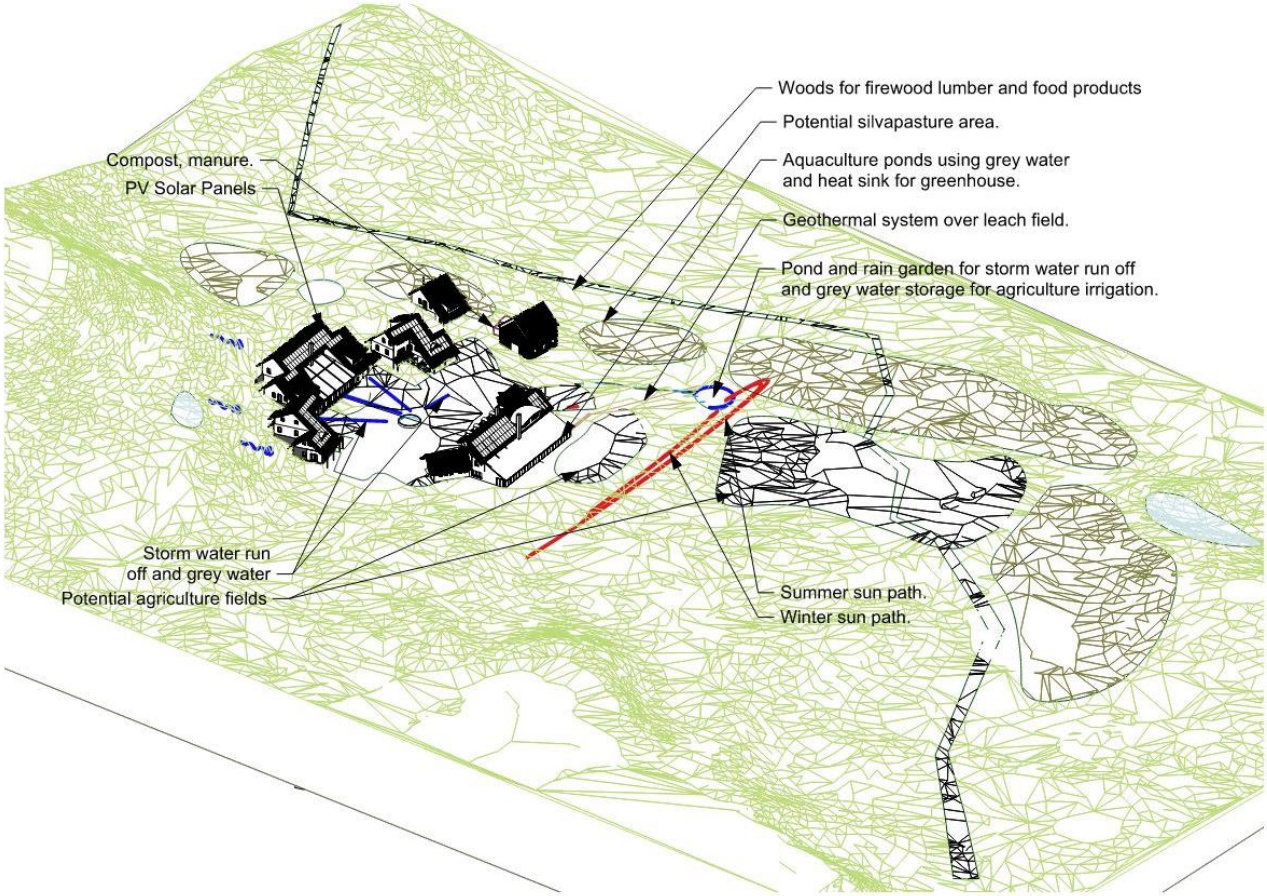
For the greenhouses, heat will be provided by the solar gain and by a wood masonry heater in each space. The floors will be linked with the earth to allow for the constant earth temperature to help modulate the greenhouse temperatures. Insulation will be used in the side walls to decouple the slab and the earth under the slab from the freezing air temperatures. An earth tube coupled with upper vents will move air in the summer from the cool northern side under the earth and up through the green house to exit through the top venting skylights. Also the septic tanks will be located next to the norther greenhouse wall and the heat generated from the bacteria in the septic tanks will heat the greenhouse.

In order encourage people to interact with nature in a regenerative way, we will have permaculture gardens closely integrated with the units and living spaces. People can pick their food on the way to their car, or to the workshop. This will increase the residents' appreciation for the food production of their land, and also for the maintenance of the plants. The placement of the plants where they are easily touched every day makes their maintenance more likely and easier. Also every resident will be required to contribute a certain number of hours per week to the agricultural production and land upkeep per week. The exact number and jobs will be left for the residents to negotiate.

An important thing to remember is that everyone has different strengths and passions, likes and dislikes. Each resident will bring something different to the table. The design of this development will need to be framework which can be adapted to support and encourage the passions and abilities of each resident. There will be much fine tunning that the residents can do. But the infrastructure and building envelops are hardest to adapt, and will need to support their full range of sustainable living from the start.

For the sacred sites, I placed one at the top of rock outcropping overlooking the buildings. This spot has the most expansive view one the property, so I wanted to take advantage of that. This spot encourages exterior contemplation of the community and of the wide spaces around. The other scared space is further in the woods, away form the buildings and fields in the hollow of a bowl. This space encourages more internal contemplation. This space also may have some historical significance.

The Atrium space gives the community additional growing space and another space for people to interact with nature, even in the depths of winter. But more importantly it is another space for community interaction. With the children's playroom in the back a small playground could be built in the atrium , or it could be used as a winter gather space, or another greenhouse, greatly increasing the food production of the community, depending on the needs and desires of the residents.



Proposed Systems Plan

Fig. 14 Proposed Systems Plan

Fig. 15 Proposed Site

Fig. 16 Perspective 1: Overall

Fig. 17 Perspective 4: Community Building

Fig. 18 Perspective 2: Residential Units and Community Building

Fig. 19 Perspective 3: Residential Units

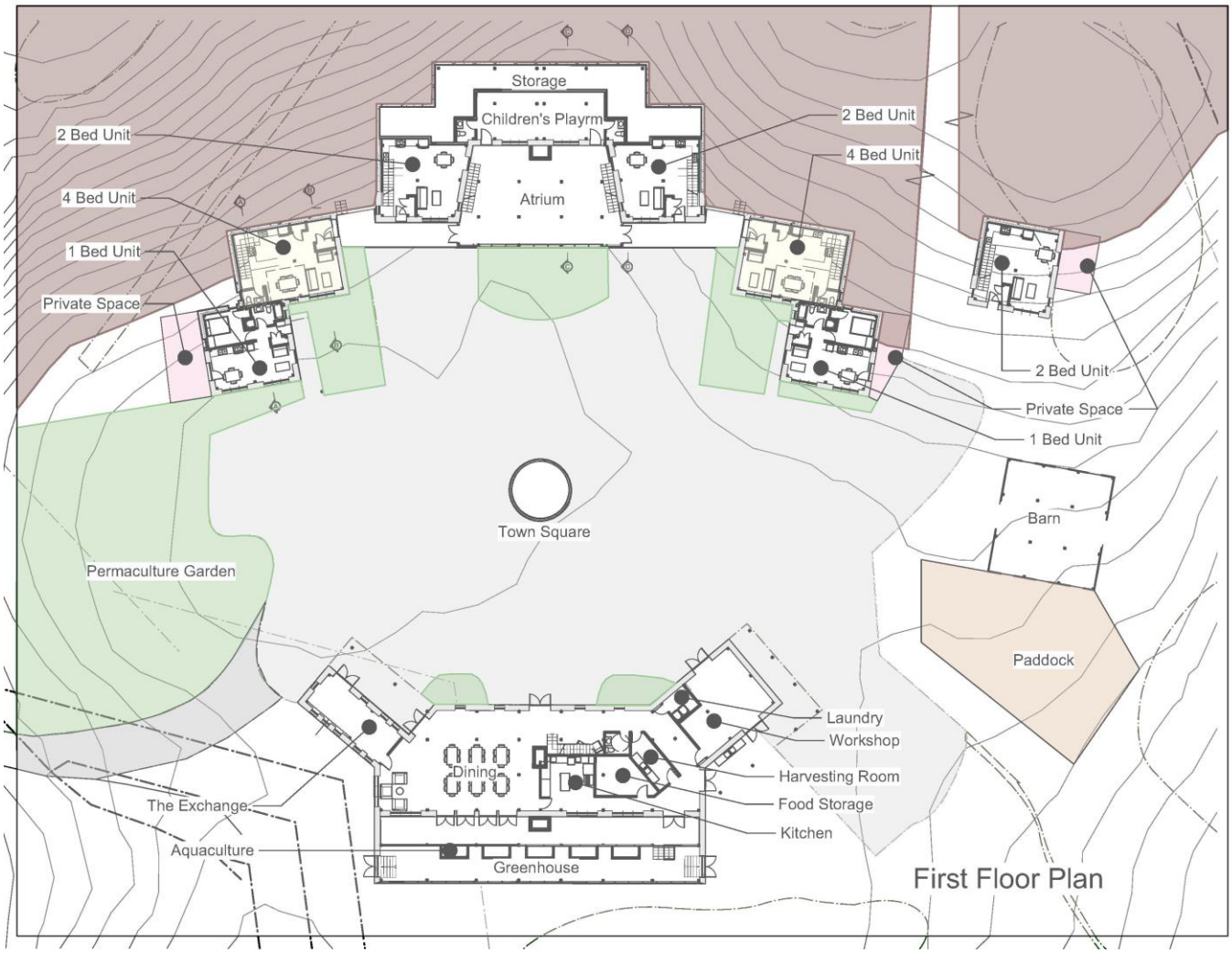


Fig. 20 First Floor

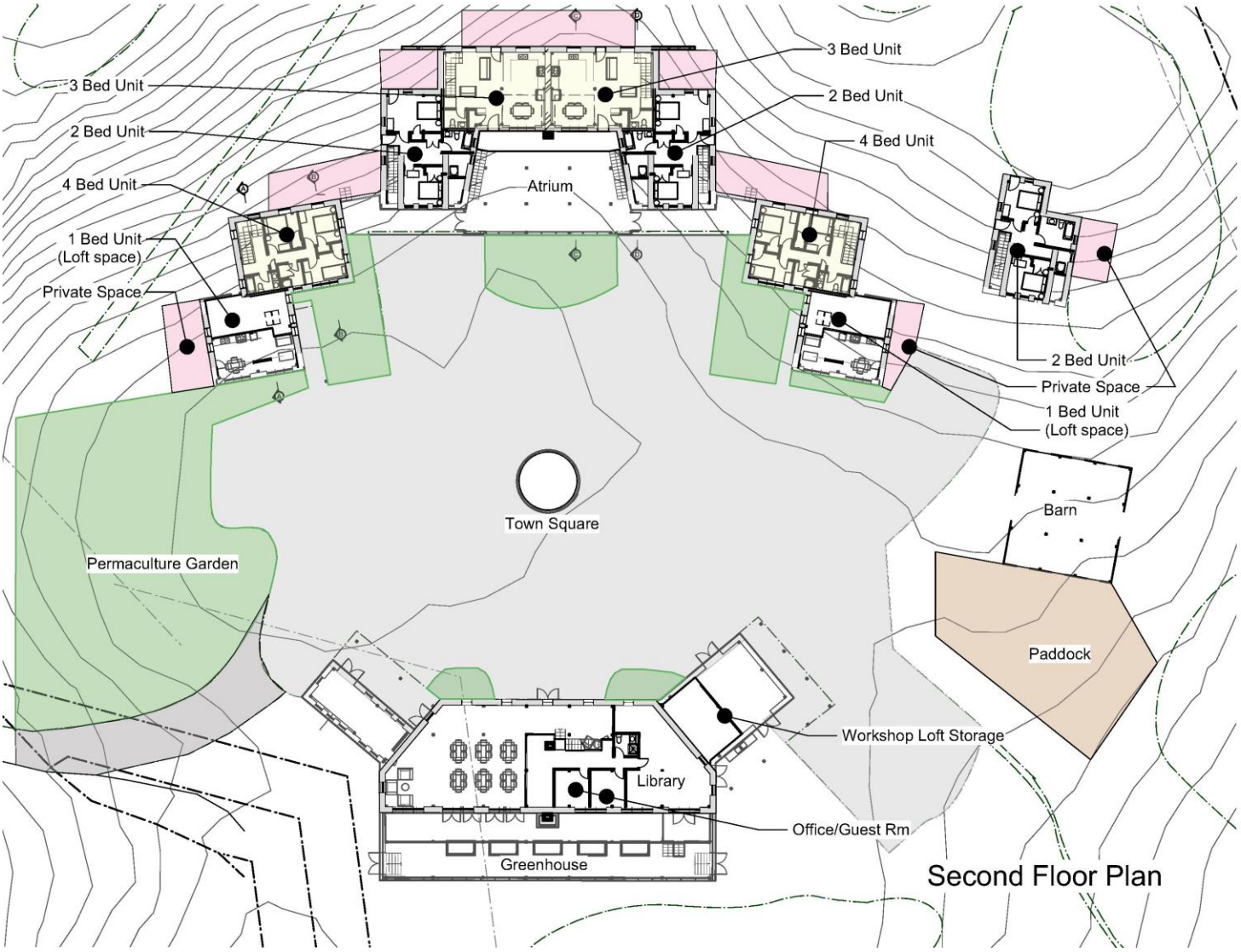


Fig. 21 Second Floor

Fig. 22 Third Floor Plan

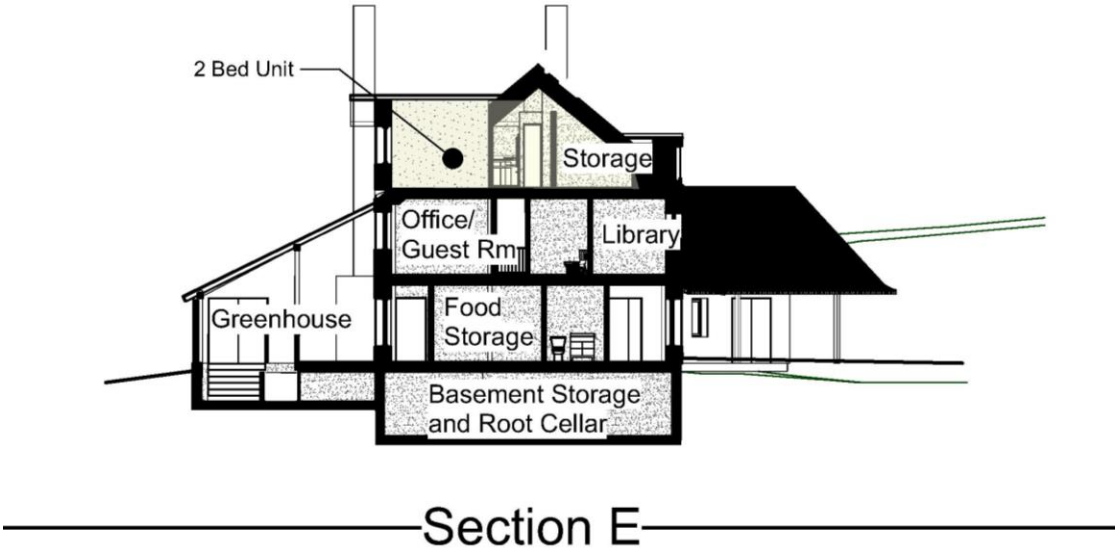
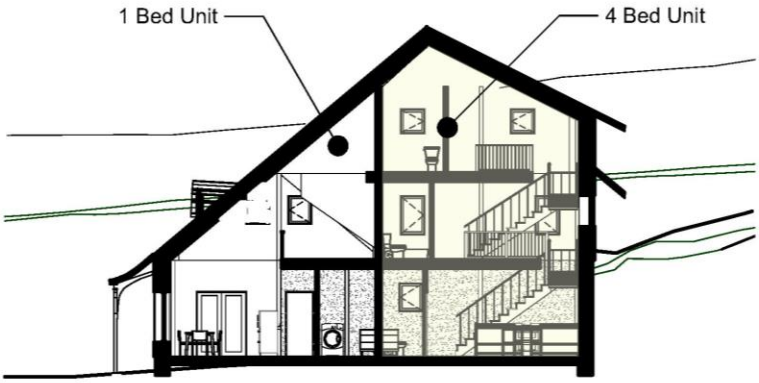


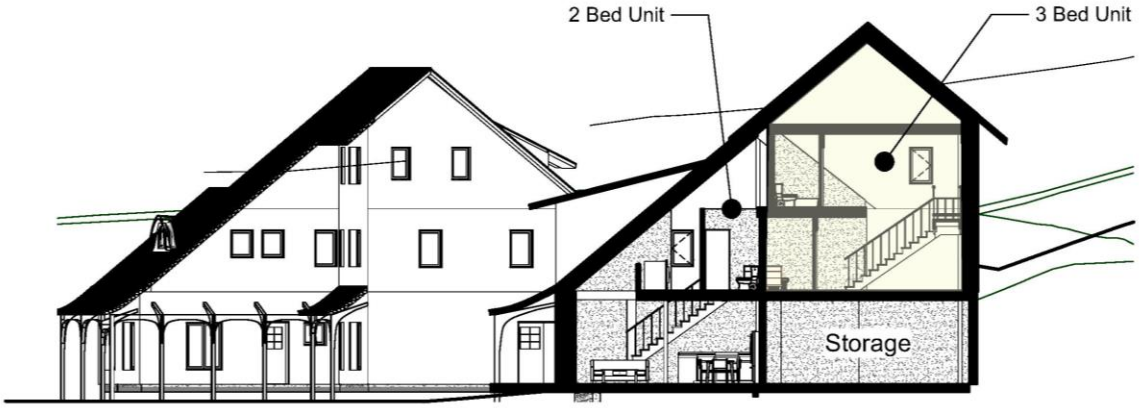
Fig. 23 Section E: Community Building



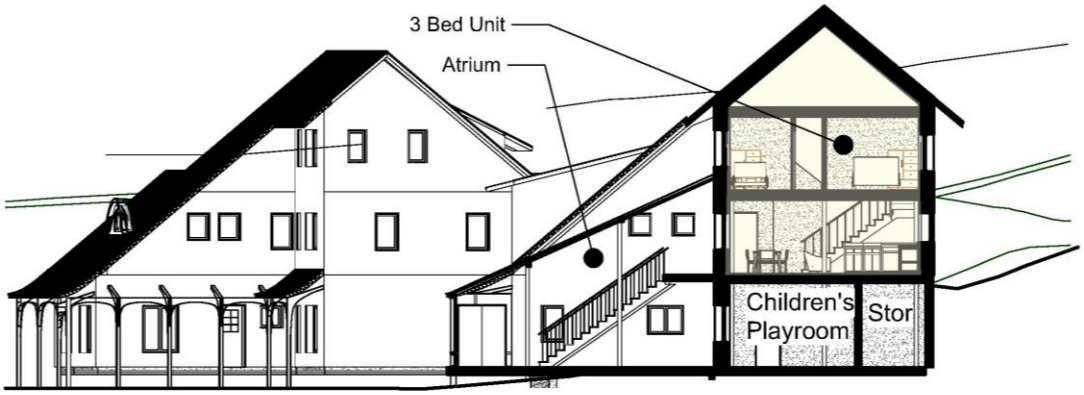
Section A

Section B

Fig 24 Sections A & B: Residential Units



Section C



Section D

Fig. 25 Sections C & D: Residential Units

Reflections

I am pleased with the overall massing and design of the project. But there is still a lot of refinement that needs to be done in the design of the spaces and facades, especially the community building. An energy calculation needs to be done to determine the exact number of PV panels the project will need to achieve net zero. Storm water calculations need to be done to determine the size of the ponds and overflow, and food consumption as well as growing space needs to be calculated to determine how much food the community will be able to grow. This project scope did not include growing all of its own food but maximizing the food production as much as possible is very desirable.

The town square concept was a late addition to the program, so I was not able to properly research it. There will need to be more work done there to understand how to soften it with greenery and encourage people to congregate in its space, while still allowing cars in. I also needed to spend more time on the design of each unit's private outdoor space.

The community building is really too big for the number of units, but I wanted to explore the full support services the client's vision called for. To fully utilize the community building as designed, the client would have needed to be successful at purchasing the adjacent lot. This additional acreage would have allowed for a total of 18 units, which would have been a better match for the community building.

I was unable to have the decision matrix integral to the design processes as I had originally intended. I also needed to chart the workflow better to more fully understand how the working spaces such as the harvesting areas and the greenhouse and the food storage should be integrated. I could have charted that flow by interviewing and visiting some farms to understand how their work flowed.

Overall though, I am very pleased with design and the direction of this thesis. I believe I was modestly successful in making the residents care about the sustainable systems the

support them. I think urban density sustainable developments in rural and suburban neighborhoods show much promise in allowing humans to live in harmony with the land.

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