2015

Low Cost Sustainable Solutions

Mara Lookabaugh
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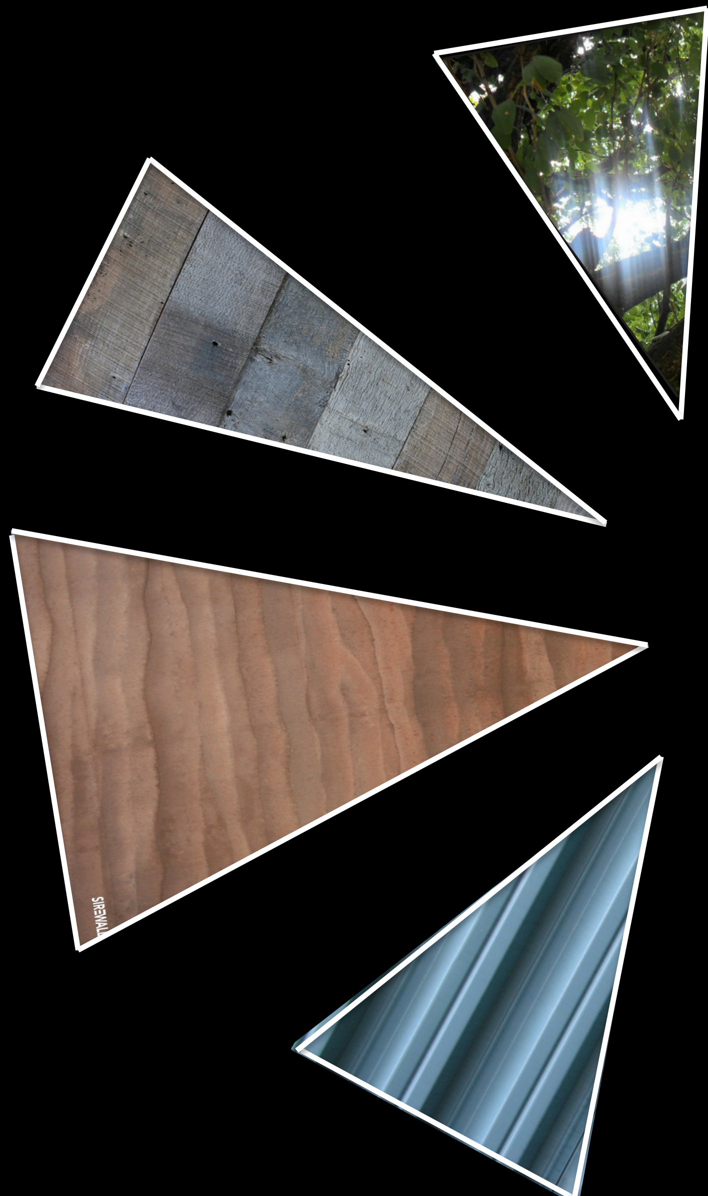
SENIOR INTEGRATIVE PROJECT: INDEPENDENT STUDY

ARCHITECTURAL STUDIES
CONNECTICUT COLLEGE
2015

CONNECTICUT COLLEGE



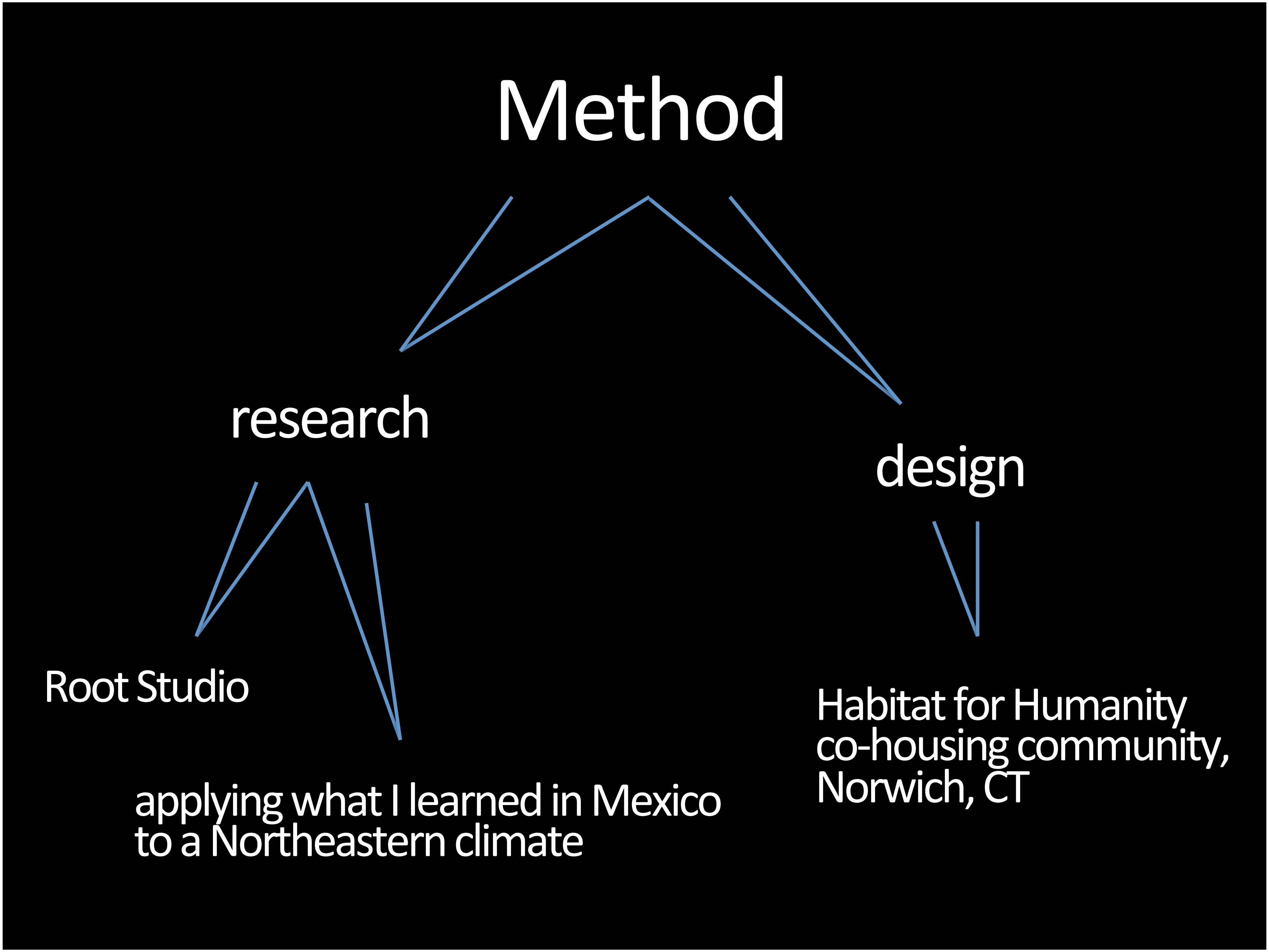
Low Cost Sustainable Solutions

Mara Lookabaugh
Senior Integrative Project, Fall 2014
Arch. Studies Department & GNCE

Ethical Reconciliation

affordable design

environmentally-responsible design


Method
research
design
Root Studio
applying what I learned in Mexico
to a Northeastern climate
Habitat for Humanity
co-housing community,
Norwich, CT

adobe construction

rammed earth construction

rammed earth house, Salisbury Cove, ME

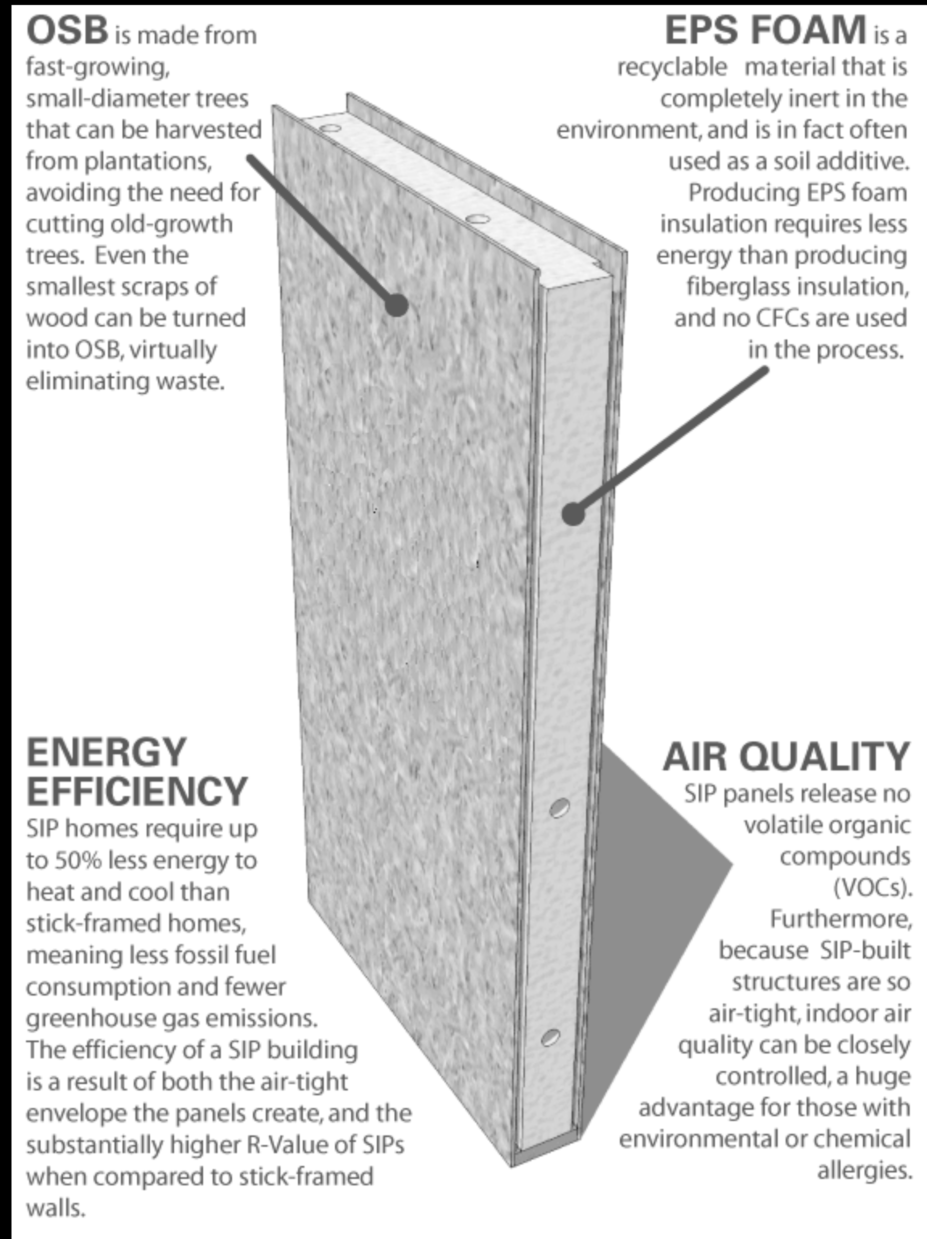
rammed earth wall,
MIT campus

reclaimed lumber

reclaimed lumber house, Portland, OR

eco-friendly prefab

Structurally-insulated panels (SIPs)



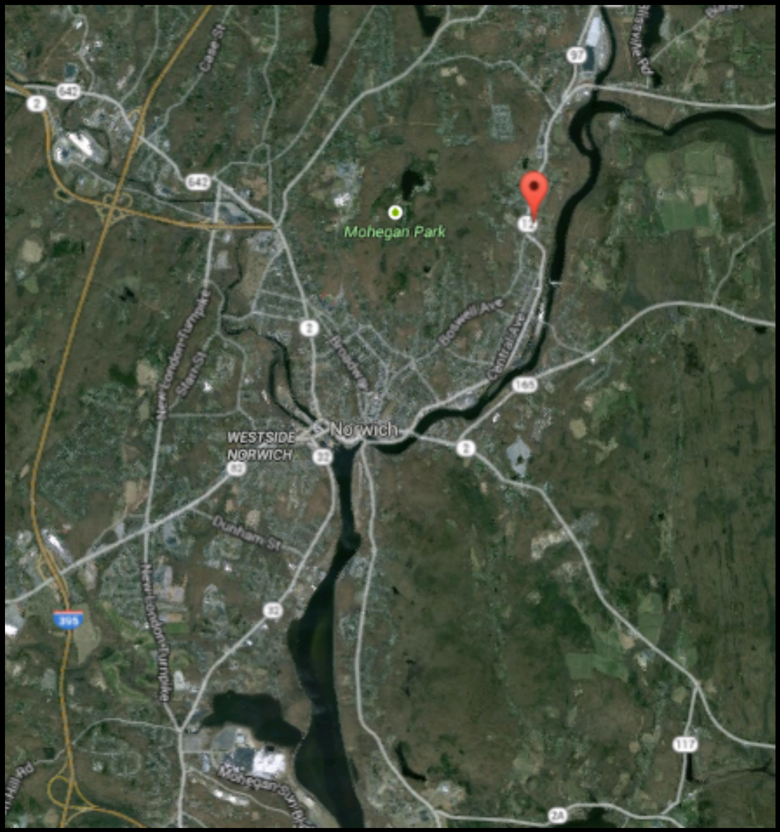
RESEARCH CONCLUSIONS

- Rammed earth, while the least environmentally intensive, is too labor and time intensive to be an efficient, low-cost building method in New England

- The combination of Structurally Insulated Panels and reclaimed lumber offers an affordable and environmentally responsible building method that references the vernacular architecture of this region.

Local design focus

Habitat for Humanity®
of Eastern Connecticut



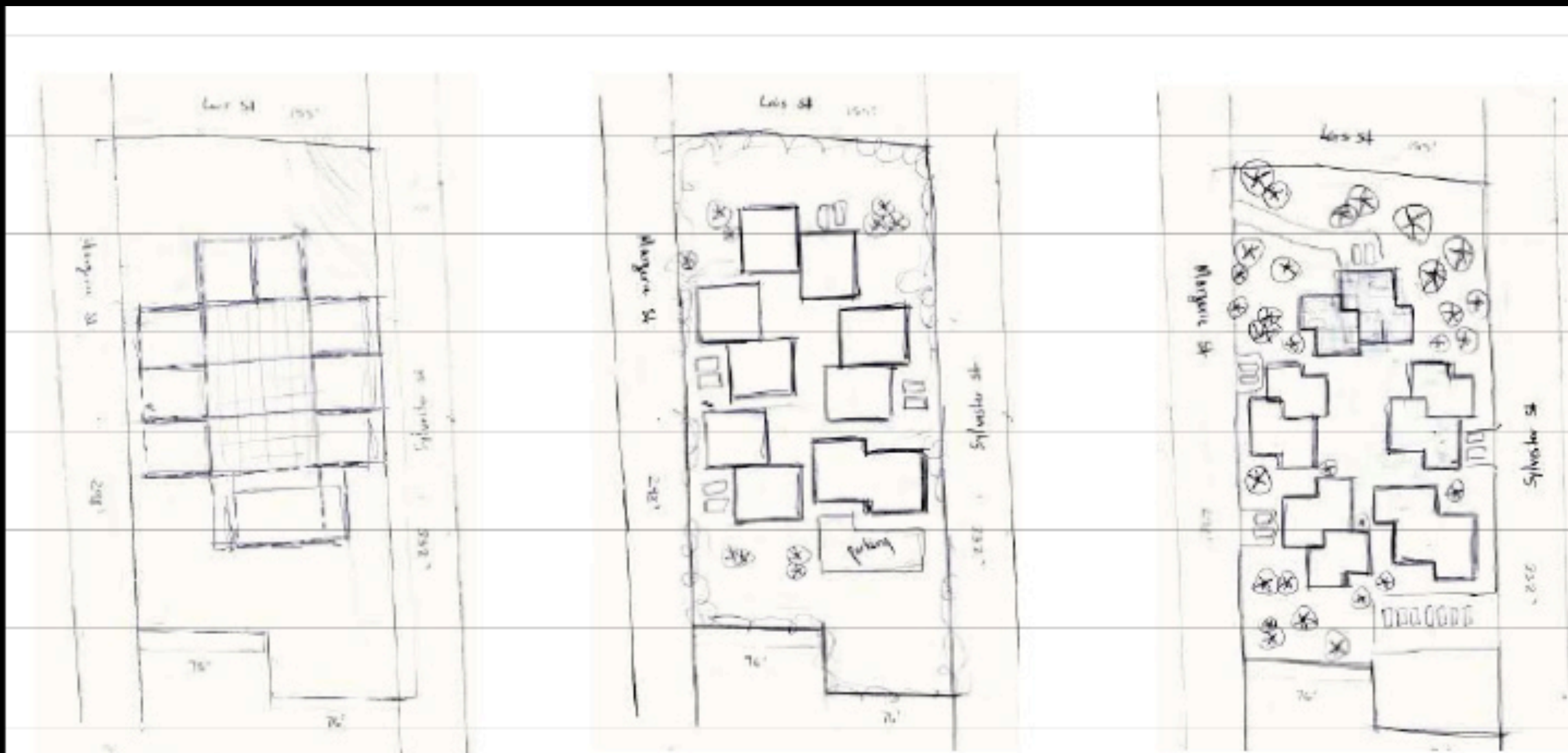
Design inspiration

Jystrup Savværk co-housing community, Denmark

Galgebakken community, Denmark

Koinania Farm

Design evolution



Concept drawing

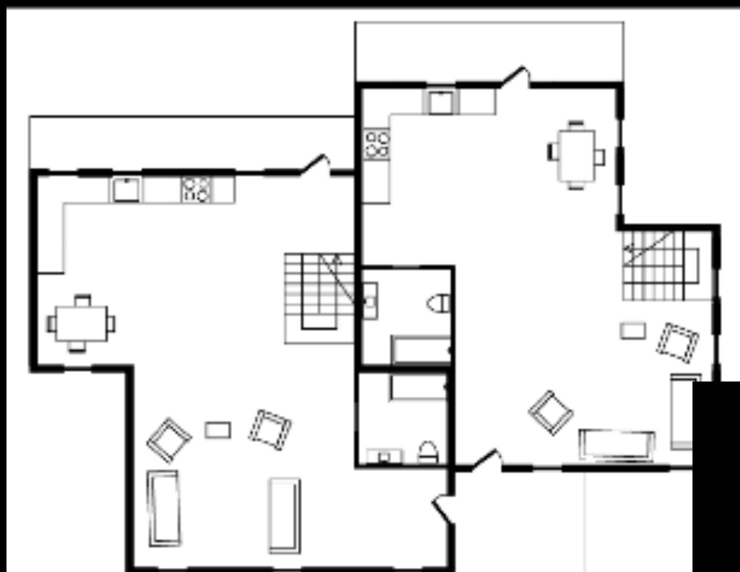
Lois Street Residences: floor plans, section

1

2

Margerie Street Residence 2: floor plans, elevations

1



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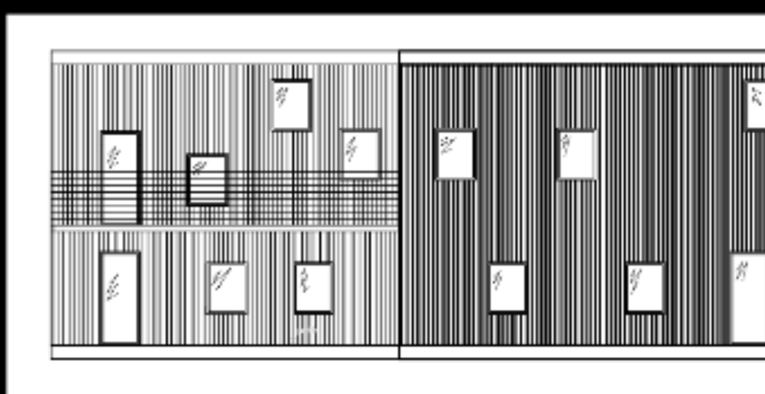
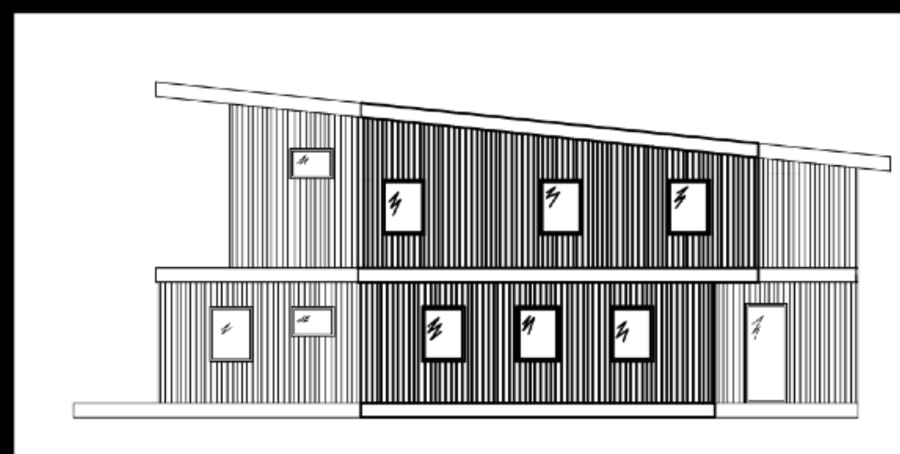
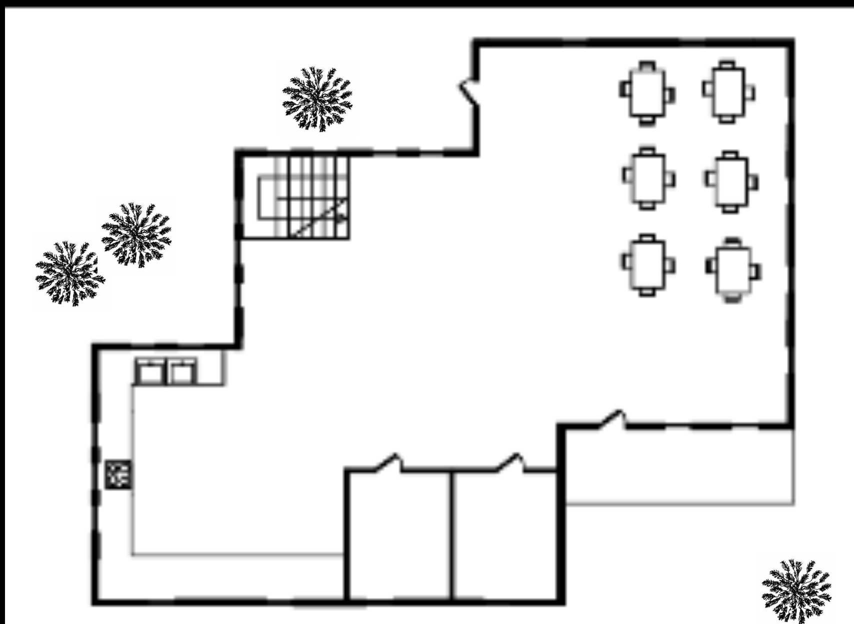




Community building: floor plans



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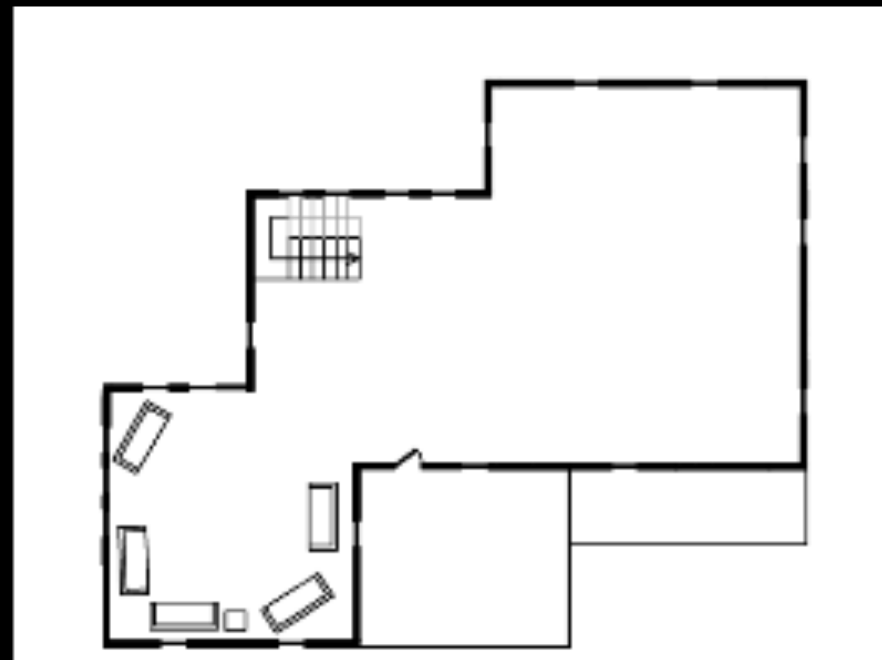

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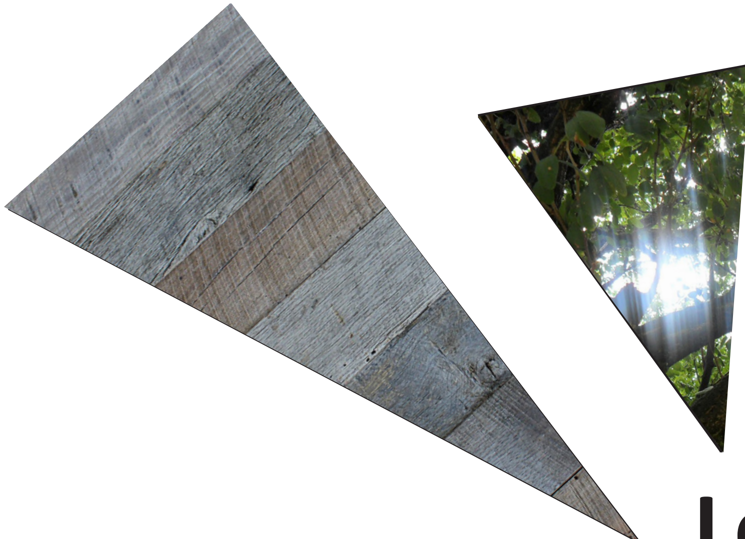
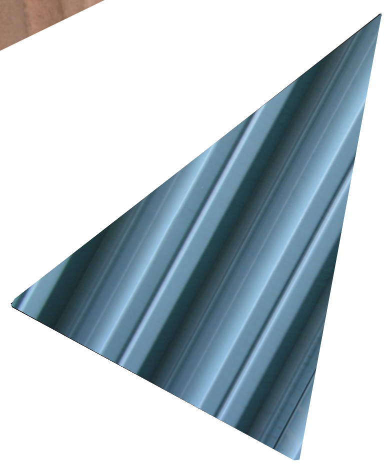
Physical model



Low Cost Sustainable **Solutions**

Senior Integrative Project
Mara Lookabaugh

Statement of Intent

The intent of my Senior Integrative Project is to uproot the contradiction between affordable design and environmentally-responsible design. The two are often at odds: sustainable design is expensive and affordable design is unsustainable. When conducting the research to undertake this project, my guiding question was primarily based in ethics: how can our moral duty to provide affordable housing to low-income families be reconciled with the ethical responsibility to secure a healthy future for our planet, and for future generations. I want to find a way to provide low-cost housing to low-income families, and also build in a way that has a low impact on the planet. My intent is to reconcile this contradiction through creative architectural design solutions.

Contents

Introduction

As a country, we are in great need of both affordable housing and environmentally responsible design.

Why we need affordable housing
In 2010, the Harvard University Joint Center for Housing released a publication stating that nearly one in seven Americans are defined as bring severely burdened by the cost of their housing, meaning that they spend more than 50 percent of their income on housing payments.[1] By providing this sector of the population with more affordable housing, we can succeed in reducing the vast economic inequality in this country.

Why we need environmentally-sustainable housing
In the United States, buildings account for 38 percent of our total carbon emissions (a larger percentage than the total transportation sector), 70 percent of total electricity used, 30 percent of total raw materials used, and 25 percent of solid waste created.[2] To ensure the health of our planet for generations to come, we need to design homes in such a way that reduces this environmental impact.

Smart design
In this project I am focusing on alternative building materials. The outer skin of a building is typically the most expensive component. In reducing the costs of these outer building materials it is possible to significantly impact the overall cost of construction. In completing this project, I acknowledge that building with better materials is only part of the solution; building truly low-cost and sustainable houses means rethinking the way we design our homes.

The best solutions are simple. We need to build smaller, exchanging square footage for higher quality materials, so as to create comfortable, interesting spaces. Many homes built today are enormous in proportion to our human bodies, making residents feel isolated and uncomfortable. We need to design regionally-specific homes that temper existing weather conditions, not work against them. Rather than overpowering the elements with energy-intensive technology, designers need to relearn how to take advantage of the best aspects of a local climate while minimizing the worst. This is passive design: design that is not dependent on energy-intensive technology to be comfortable. There are many design elements that can be incorporated with passive design:

> Building small: smaller homes cost less to heat and cool.

> Capitalizing of daylight: designs should maximize the winter sun and reduce the powerful heat of afternoon sun.

> Natural ventilation: this effect can be achieved by strategically placing operable windows and doors to direct airflow on a site.

> Selectively used heat gain: best achieved through window placement. A north/south orientation is typically best with most windows facing south. It is best to minimize windows facing west to prevent excessive heat gain in the afternoon.

Building with Reclaimed Lumber

And other recycled materials

To build in a more environmentally responsible way that costs less, it is imperative to explore building with recycled materials. In any structure that is ready to be dismantled, many or most of the materials can be salvaged and reused in a new home construction project. This environmentally friendly process is called "deconstruction" in contrast to demolition which send tons of debris to landfills.[3] With deconstruction, a building is taken apart in a way so that every component of the building that can be reused, re-purposed or recycled. The process of recycling is inherently sustainable because it both reduces the amount of resources necessary to produce new building materials, and re-using these already-made materials means we can produce less waste. It is especially important to recycle lumber. The EPA estimates that more than a billion board feet of lumber is simply thrown away each year.[4] Apart from the environmental and economic advantages to building with reclaimed lumber, this type of old-growth wood is often more structurally sound compared with lumber on the market today.

Old growth forests have been over-logged for centuries and there are very few of these old forests left. Conservation efforts offer the solution of "managing" forests, the outcome of which is forests full of "new growth" trees. Today, the lumber that we build with is usually logged from these relatively young forests. The difference in density and stability of a new growth tree compared to an old growth tree is large.

Over time, trees have to withstand the forces of nature - strong winds, inclement weather, shifting terrain - all of these factors make a tree stronger. Because there was less carbon dioxide in the atmosphere when old-growth trees were planted, the trees grew much more slowly. That slow growth created a dense cellular structure and is why many old growth barn timbers have held up for hundreds of years.[5]

Figure 1

Sourcing and Construction

Building with salvaged materials costs between 10 and 50 percent less than buying comparable new materials.[6] In some cases, the owner of an dilapidated building will allow people to simply take whatever they can safely remove. This makes the take-down process a little easier for the owner, with less material to deal with, and the person salvaging receives the materials that cost nothing more than time and labor. This process of finding and re-using, like rammed earth construction, is more time-intensive that building with store-bought, new materials, its takes research and planning, but the outcomes are well worth the added time and consideration that goes into a building.

Wood is the most commonly salvaged material because it is so ubiquitous in both old and new construction. Wood can be salvaged from all different areas of a building: siding, structural timbers, existing wood flooring, interior paneling, doors, etc.[7] Reclaimed lumber, depending on its makeup can be used as both a structural and non-structural building material. The best reclaimed portions to use as structural support are old timbers and beams. These pieces of wood they are so inherently sturdy and sound because when there were first employed, they were harvested from the strongest among a forest of the old-growth trees. As such, reclaimed timber often exceeds the structural qualities necessary to meet local building codes because codes now are based on much younger and less sturdy trees.

However, not all reclaimed timbers can be grade-stamped at their original grade level due to bolt holes or other conditions. An architect or structural engineer should perform load and bearing calculations before beginning construction.

The most affordable method of salvaging materials is to find an abandoned building (or part of a building that is being redone or renovated) and an owner who is willing to have materials salvaged at no cost. This option is the most labor intensive and requires following proper safety precautions. The second best option, which is much less labor intensive, is to find a local retail or wholesale salvage company. There are numerous reclaimed lumber companies here in Connecticut, such as Armster Reclaimed Lumber in Guilford, CT or Connecticut River Lumber Co., in Old Saybrook, CT.

Building with reclaimed lumber entails doing research, and such, any homebuilder should look at the amount of prep work that would be required to make the material project ready. If the wood is being salvaged from an abandoned building, it is important to first know the history of that building. Unfinished wood in an early twentieth century factory may have been exposed to high levels of toxic chemicals. Before using any material it is critical to check for structural integrity and any obvious signs of damage.

The Backyard House

In building the Backyard House in Portland, OR, the architect Morgan Lea was inspired by Bernard Maybeck's 1931 "Mistake House" at Principia College in Elsah, Illinois[8] which was built with multiple, varying materials to display the different types of construction used in building the College. The Backyard House has a similar function. It is both a small house and a display of how building with reclaimed lumber is both a sustainable and affordable method of construction. The wood for the house was donated by three local barns in Oregon and the copper roof was found by the architect on craigslist.

Figure 2

Figure 3

Eco-friendly Prefabricated Construction

Prefabrication: background and today

Prefabricated construction involves the transportation of building parts manufactured in a factory to a site where they can be assembled into a finished building. There are examples of this type of construction in America as early as the early English settlement in Cape Ann, MA, where they made panelized fishing sheds in 1624.[9] The real increase in this type of building came with the Industrial Revolution, as industrialized, mass-produced materials typically lend themselves to prefab construction. Elements such as cast iron, structural steel, large sheets of glass can be manufactured off site, and then easily assembled on site. Between 1908 and 1940, catalog giant Sears Roebuck and Company sold more than 100,000 prefab home kits to Americans.[10]

Figure 4

After WWII, the government subsidized prefabricated housing. It was quick and economical in a time of increased housing demand in the U.S. However, as time passed, people began to associate prefab housing with cheap, inferior quality housing and bad design.[11]

Today, with so many people severely burdened by their housing costs we have a similar need for affordable housing. And with the increased impact that humans and housing place on the natural environment, that affordable housing needs to be environmentally conscious as well. Eco-friendly prefab "explores the intersection of sustainable design, affordable housing and prefabricated construction".[12] It involves the creation of prefabricated homes that are regionally-specific, use natural ventilation and lighting and are built with sustainable and locally-sourced materials in a factory setting and then transported to site.

Modular Technology

The process of off-site modular construction is inherently sustainable. There is less energy consumed because workers are not traveling to the site and from the site for the duration of the construction process. With modular construction, building materials can be used more completely, and more efficiently, producing less waste. Building in a factory allows for precision cutting, so each cut is done right the first time. Modular home construction achieves 50 to 70 percent less waste compared with on site-construction.[13] The finished modular product is more tightly constructed and thus more energy-efficient than a site-built home.

As manufacturing technology has advanced, residential design has pursued more complex prefab components. Today, complete homes or engineered modules can be built off-site in a climate controlled factory environment, and then transported on trucks, ferries or trains to a building site, where they are set onto a site-built foundation.[14] This method of construction is much more time-efficient than regular onsite construction. When Michelle Kaufmann, author or PreFab Green, and her husband decided to build their modular home they did a comparison between the two building types - between offsite and onsite construction. They found that the offsite home not only took significantly less time to build, but they were also able to build their home at a cost of 15 percent less than a site-built house.[15]

Customization and Construction
In the prefabrication process, customization can happen at many levels. This individuality starts with the floor plan and also includes roof type and materials used. A modular home is constructed from the inside out. This technique, in a factory, allows many people to work on different aspects of the house at the same time, including inspectors to review each step of the home building process to ensure the highest quality.

The most affordable prefabricated construction technique is to build with Structurally Insulated Panels (SIP'S). SIP's are a high performance building system for residential and light commercial construction. The panels consist of an insulating foam core (EPS) sandwiched between two structural facings, typically oriented strand board (OSB). SIPs are manufactured under factory controlled conditions, reducing waste at the construction site.[16]

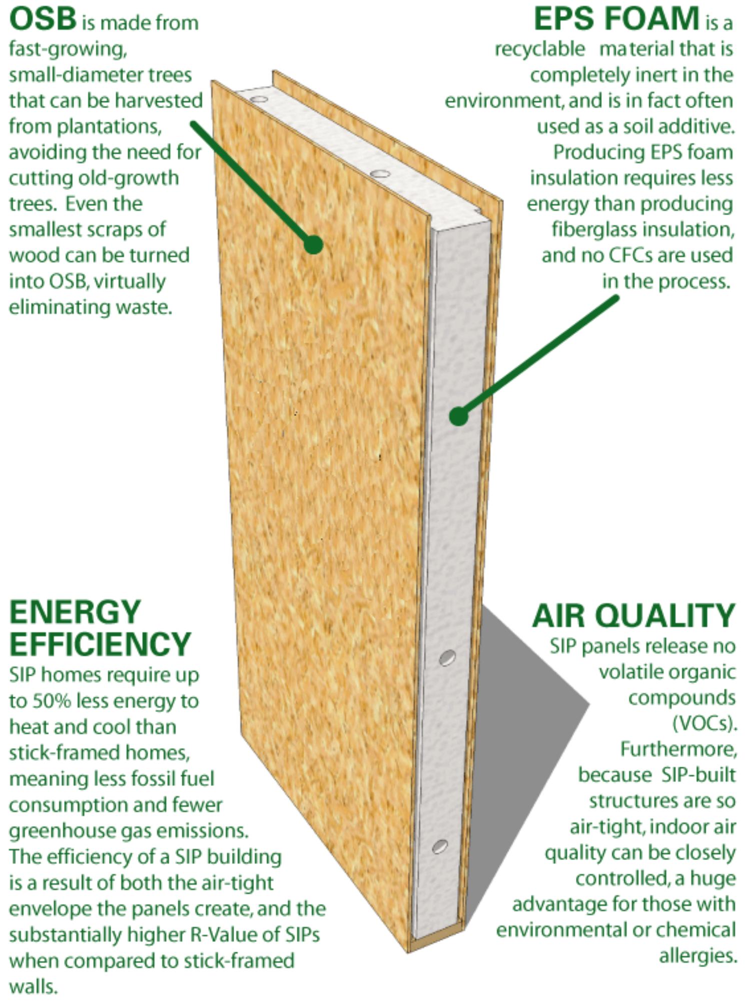


Figure 5

Building with SIP's generally costs about the same as building with wood frame construction when you factor in the labor savings resulting from shorter construction time and less job site waste. Other savings are realized because smaller heating and cooling systems are required with SIP construction."[17] Ensuring that prefabricated, modular housing has potential as a low-cost and environmentally-responsible building method entails rethinking the materials used. There are many prefabrication companies in Connecticut who pride themselves on being environmentally responsible and would be open to incorporating sustainable elements like SIP's and reclaimed lumber into their modular homes.

Prefab homes as the way of the future
Prefabrication and modular technology offers an educational opportunity. Alastair Parvin developed WikiHouse, an open-source construction system. His system contradicts the age-old trend in architecture that is to design for about the richest one percent of the world's population. Parvin's idea behind WikiHouse is to switch that model from the one percent to the 100 percent. He offers a solution to this problem through the democratization of production, an idea inherent in communist and socialist theories. To make production democratic, Parvin come up with the idea of open source software and open source hardware, which are freely shared blueprints of houses that anyone can download and make for themselves. In Parvin's words:

> "What these technologies are doing is radically lowering the thresholds of time and cost and skill. They're challenging the idea that if you want something to be affordable it's got to be one-size-fits-all. And they're distributing massively really complex manufacturing capabilities. We're moving into this future where the factory is everywhere, and increasingly that means that the design team is everyone. That really is an industrial revolution. And when we think that the major ideological conflicts that we inherited were all based around this question of who should control the means of production, and these technologies are coming back with a solution: actually, maybe no one. All of us."[18]

His idea is to make it possible for anyone to go online and access a free shared library of 3D models of houses, that can be printed out in modular sections using a CNC machine which cuts plywood into predetermined shapes. All the parts are numbered and can be put together using wedge and peg connections rather than using bolts. In Parvin's model, a team of two or three people can build a small house in about a day without any traditional construction skills, and without a huge array of power tools. This is truly the model of affordable and sustainable construction of the future, one that is available to anyone.

Local Focus: Habitat for Humanity Co-housing Community
Norwich, CT

Associated with each of the design solutions that I have researched is a re-conception of traditional housing construction. We need to reconsider the materials with which we build our homes, and the scale at which we build them. A truly sustainable design is not one that is out of reach of the average citizen. Sustainable design needs to be affordable, use less resources and less space.

To give my research a local design focus, I worked with the Eastern CT chapter of Habitat for Humanity to create a design for a co-housing community that will be built in Norwich, CT. My design evolved over the course of the semester in consideration of the site, of the desired size of the community, and in attempt to choose the most sustainable building materials, environmentally and economically. Inspiration for my design includes co-housing communities that I visiting during my semester abroad in Copenhagen, Denmark, and was also guided by the philosophy behind and the birthplace of HFH, Koinonia Farms.

My proposal for this 8 home community explores the option of using reclaimed lumber for the exterior siding of my houses, and SIP's as the framework construction method. For structures built with reclaimed lumber this type of factory-based, modular construction makes the most sense because many of the reclaimed pieces of wood need to be re-cut to fit specific needs, and this is more easily done indoors in a factory, rather than onsite. Prefabrication makes a lot of sense environmentally and economically, but especially in terms of multi-family housing designs such as the community of homes in Norwich.

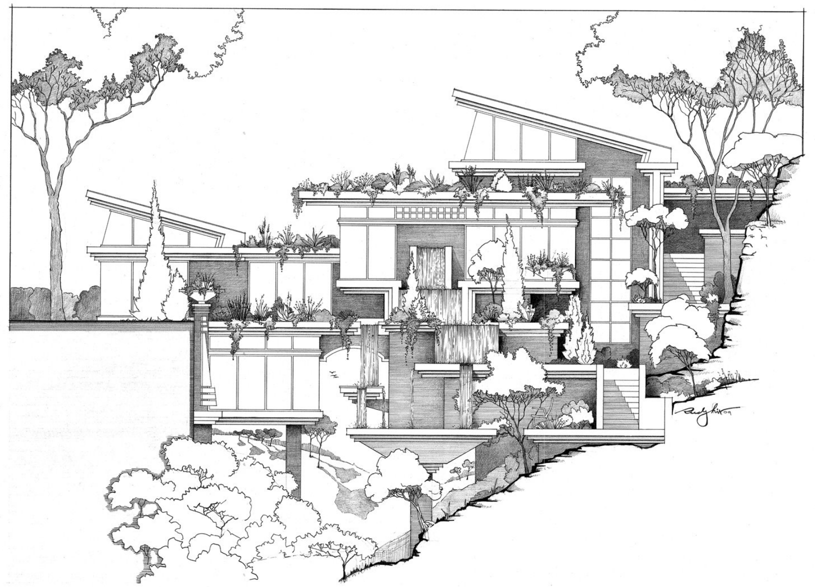
Habitat for Humanity families often work full time and as such, the materials used in their homes must be long-lasting and low maintenance, as they do not have the time or the money for upkeep of materials. My design employs SIP construction with metal roofing. Compared with other types of roofing, metal roofs are low-cost and sustainable. Metal roofing is protected by highly durable paints and coating, ensuring a lifetime of 40 years of more and protection against severe weather. Metal roofing contains 25-95% recycled materials and is virtually 100% recyclable. Metal is also very energy efficient. ENERGY STAR-labeled metal helps lower heating and cooling costs.[19]

Figure 6

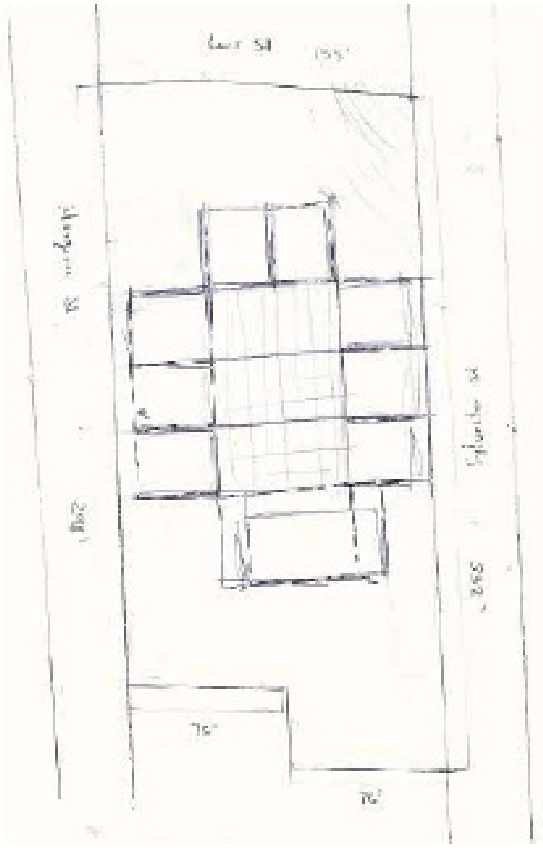
In my design, many of the dwellings are attached, meaning that total material and land usage can be reduced, and many energy systems can be shared. The eight acre site has space left over to leave as a central, shared courtyard.

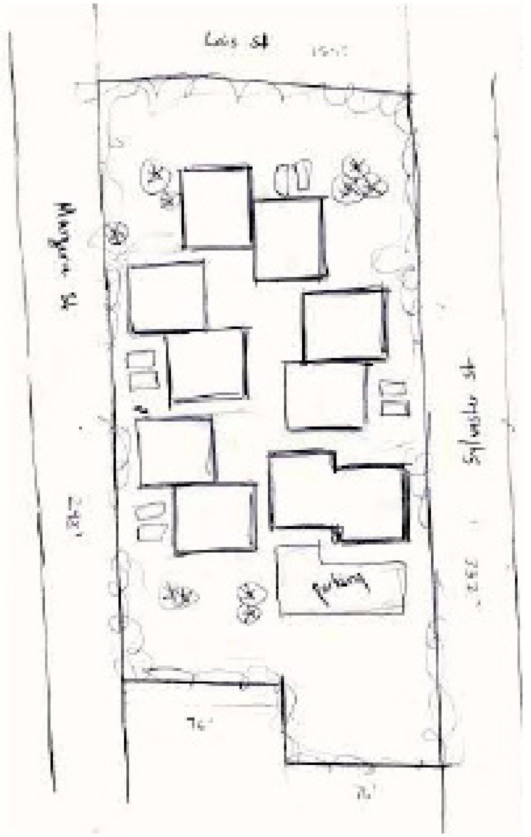
Jystrup Savværk co-housing community, Denmark

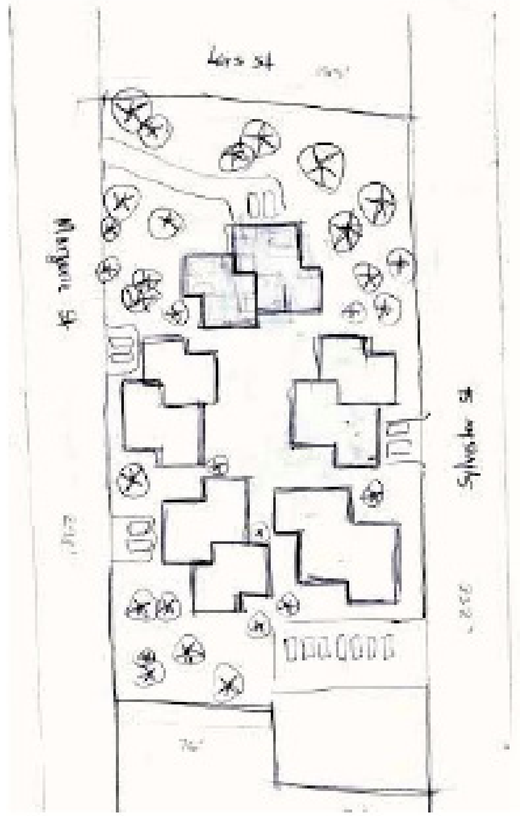
Galgebakken community, Denmark



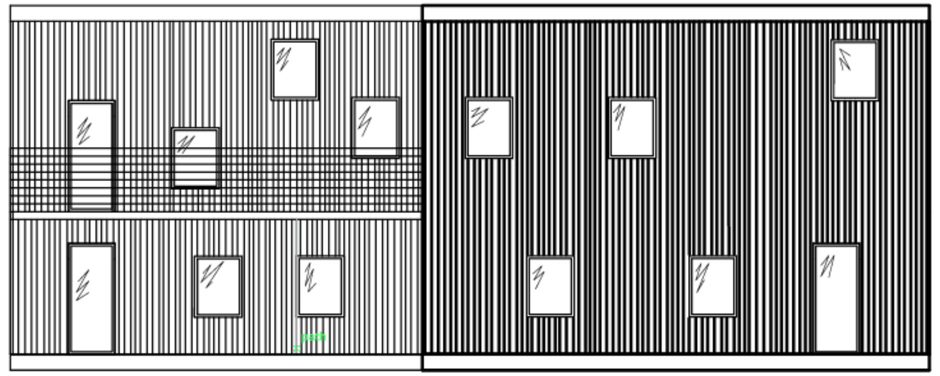
Koinania Farm



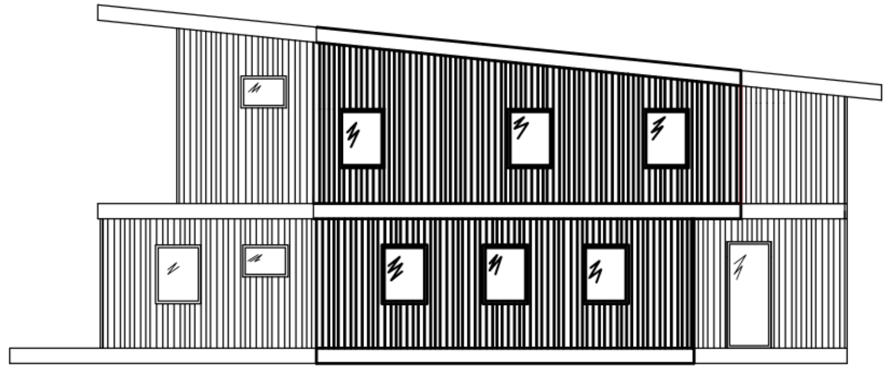




Lois Street Residence Section

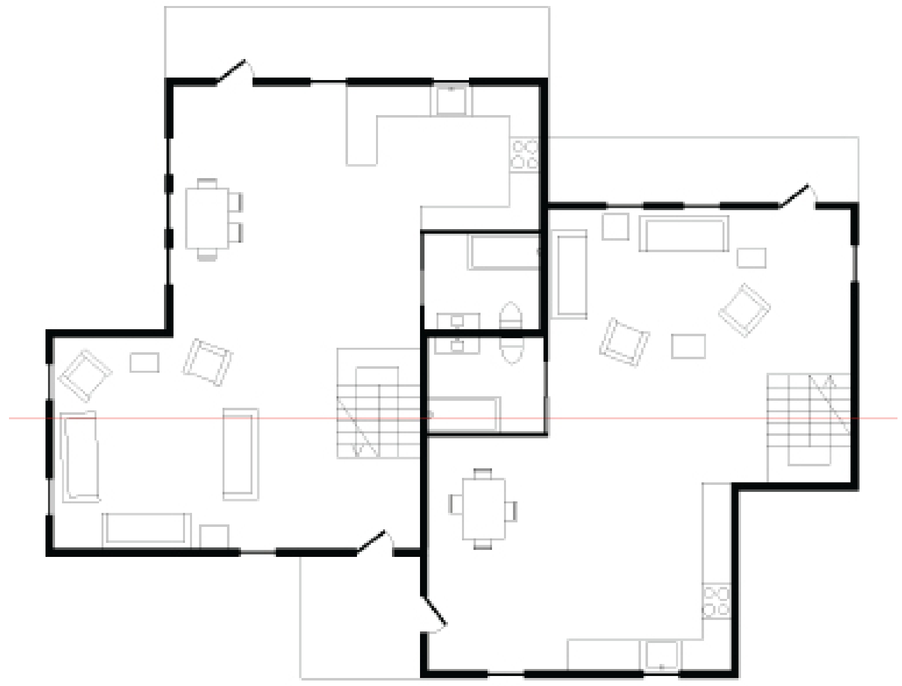


Margerie Street Residence 2 East Elevation



Margerie Street Residence 2 South Elevation

Lois Street Residence Floor Plans



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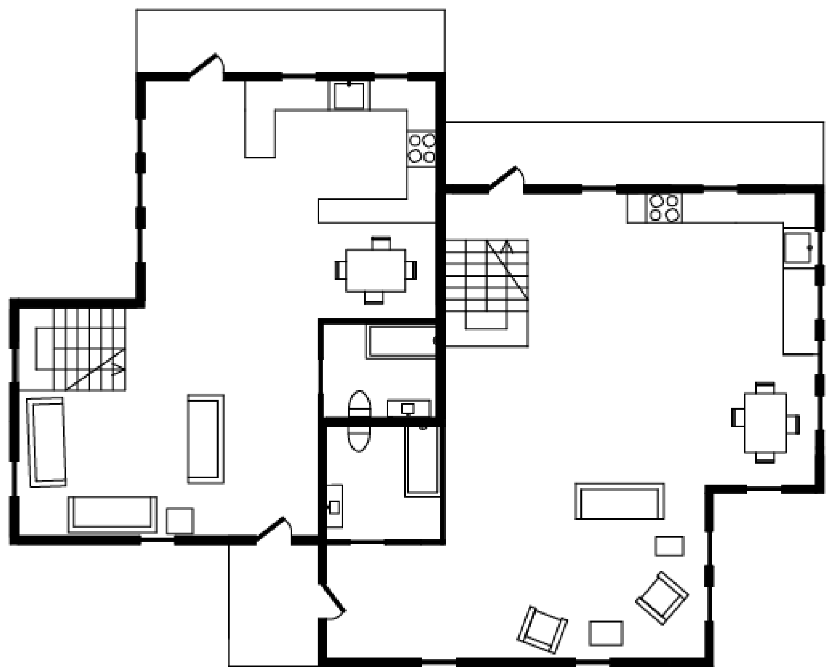
Margerie Street Residence 1 Floor Plans



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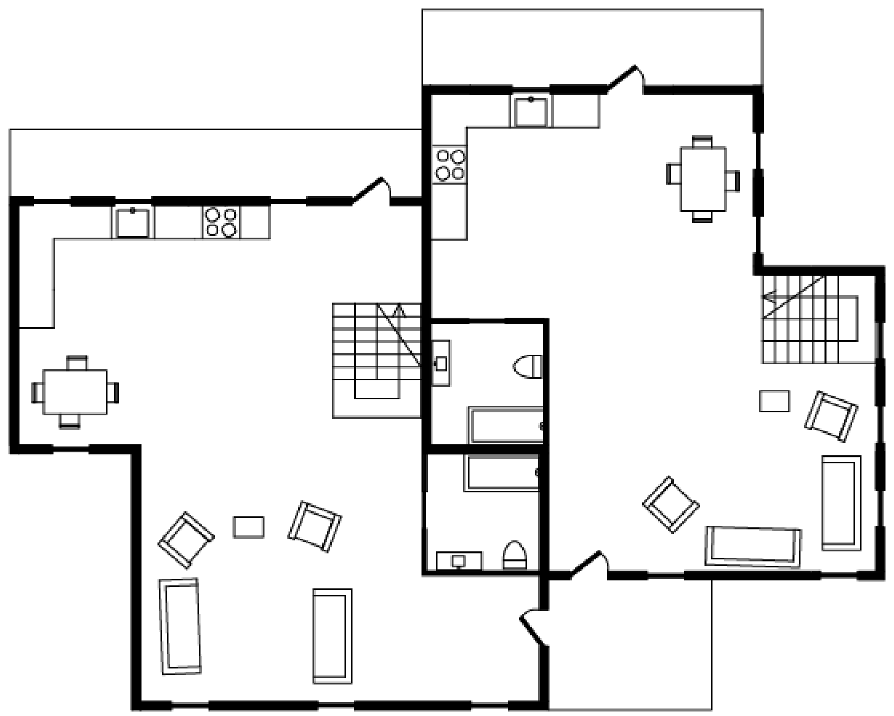
Margerie Street Residence 2 Floor Plans



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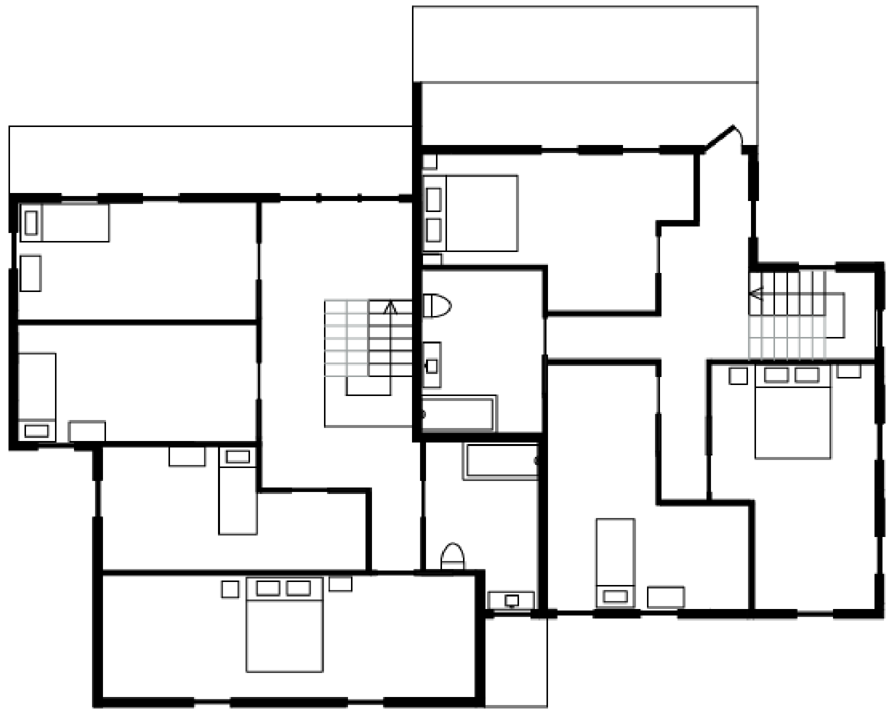

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Sylvester Street Residence Floor Plans

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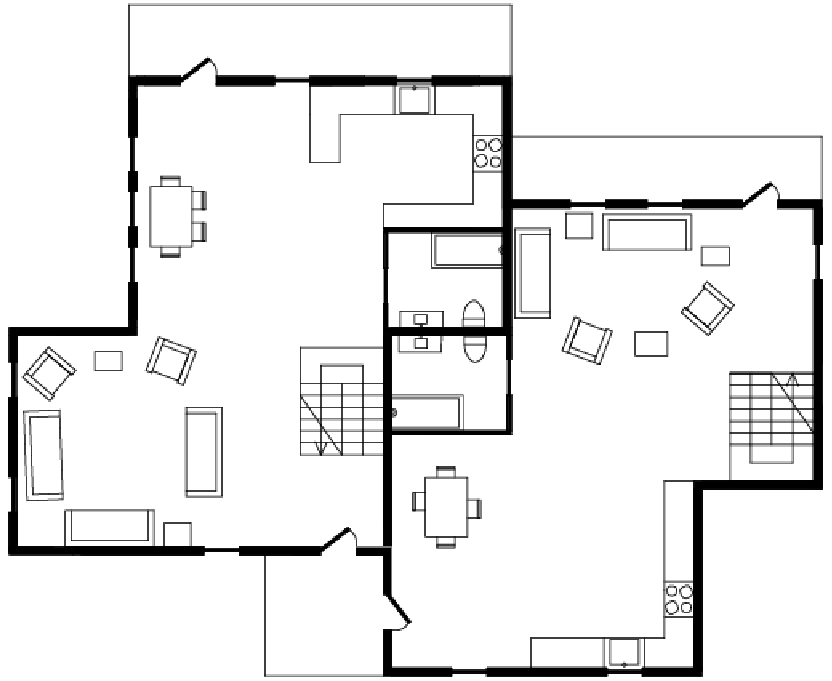

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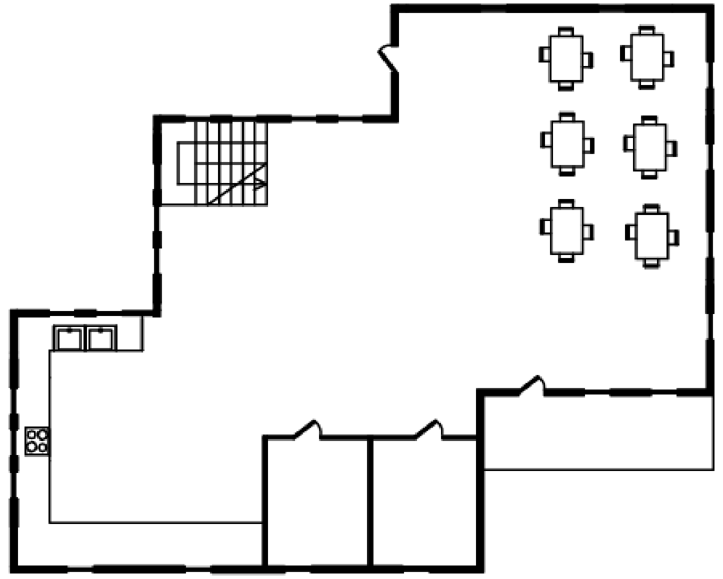
Community House Floor Plans



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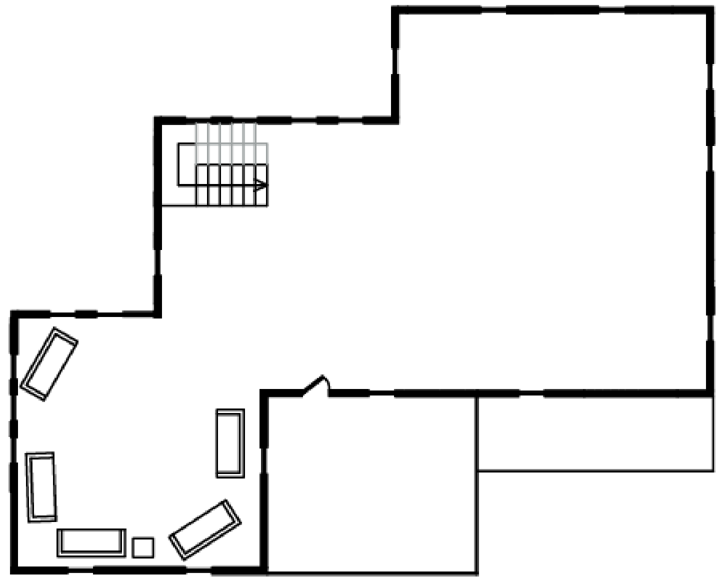

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[4] *Ibid.*
[5] *Ibid,* 28.
[6] *Ibid,* 9.
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[8] Casimiro, Steve. "The Backyard House." Adventure Journal. 29 June 2012. Web.
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[15] *Ibid,* 17.
[16] "Green Building with SIPs." SIPA. Web. http://www.sips.org/green-building/green-building-with-sips. 17 Nov. 2014.
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Figure 1: "Guilford Barn." Historic Barns of Connecticut. CT Trust for Historic Preservation, Web. 20 Dec. 2014.

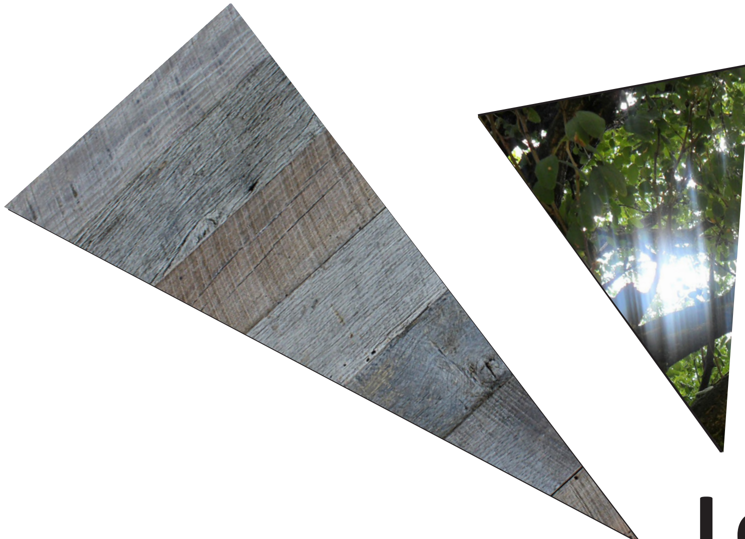
Figure 2: "The Mistake House (1931)." Maybeck and Principia College. Principia College, Web. 14 Nov. 2014.

Figure 3: Casimiro, Steve. "The Backyard House." Adventure Journal. 29 June 2012. Web.

Figure 4: "Homes Index - No. 147." Sears Archives. Sears.com, Web. 7 Nov. 2014. <http://www.searsarchives.com/homes/bydate.htm>

Figure 5: "Structural Insulated Panels." Heavy Timber Truss & Frame, Web. 18 Dec. 2014. <http://heavytimbers.com/sips.html>.

Figure 6: "Metal Roofing Connecticut." Metal Roofing Connecticut. Web. 14 Jan. 2015. <http://www.metalroofconnecticut.com/>.



Low Cost
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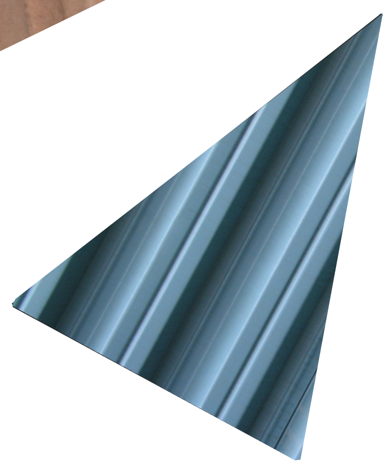

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Introduction

As a country, we are in great need of both affordable housing and environmentally responsible design.

Why we need affordable housing
In 2010, the Harvard University Joint Center for Housing released a publication stating that nearly one in seven Americans are defined as bring severely burdened by the cost of their housing, meaning that they spend more than 50 percent of their income on housing payments.[1] By providing this sector of the population with more affordable housing, we can succeed in reducing the vast economic inequality in this country.

Why we need environmentally-sustainable housing
In the United States, buildings account for 38 percent of our total carbon emissions (a larger percentage than the total transportation sector), 70 percent of total electricity used, 30 percent of total raw materials used, and 25 percent of solid waste created.[2] To ensure the health of our planet for generations to come, we need to design homes in such a way that reduces this environmental impact.

Smart design
In this project I am focusing on alternative building materials. The outer skin of a building is typically the most expensive component. In reducing the costs of these outer building materials it is possible to significantly impact the overall cost of construction. In completing this project, I acknowledge that building with better materials is only part of the solution; building truly low-cost and sustainable houses means rethinking the way we design our homes.

The best solutions are simple. We need to build smaller, exchanging square footage for higher quality materials, so as to create comfortable, interesting spaces. Many homes built today are enormous in proportion to our human bodies, making residents feel isolated and uncomfortable. We need to design regionally-specific homes that temper existing weather conditions, not work against them. Rather than overpowering the elements with energy-intensive technology, designers need to relearn how to take advantage of the best aspects of a local climate while minimizing the worst. This is passive design: design that is not dependent on energy-intensive technology to be comfortable. There are many design elements that can be incorporated with passive design, such as natural ventilation and selectively used heat gain. By building our houses smaller, considering the conditions of the local environment and capitalizing on these natural forms of energy, it is possible to significantly reduce financial and environmental costs.

Preface

This past summer I worked as an intern at Root Studio, an architecture firm in the city of Oaxaca, Mexico. The solution that Root Studio applies to the issue of designing low-cost and sustainable homes is not a new idea, as civilizations have been building this way for thousands of years.

In much of Mexico there is a rich, cultural tradition of architectural construction that is inherently low-cost and sustainable because the core material is earth. Adobe is one of the oldest building materials. This type of construction is durable, sustainable and low-cost. By building with a local, and basically free material, many rural and impoverished villages in Mexico have been able to sustain and develop. Despite the advantages of adobe as a building material, adobe is being progressively replaced by industrial materials. These modern, industrial materials, such as steel, concrete and glass lack context in the Mexican climate, landscape and vernacular tradition. With this process of modernization, indigenous peoples are losing the skills to build in the traditional methods. This process is especially concerning in areas with limited resources.[3]

The mission of Root Studio is to reinstate and reteach the traditional building methods of Southern Mexico to the people that live there. By doing this they are promoting an architecture that is sustainable in terms of cost and resources and at the same time, empowering a culture by teaching them the skills necessary to build their own homes and cities, and building in a way that has a very low impact on the natural environment.

Figure 1: Internship with Root Studio

My internship with Root Studio laid the groundwork for my research. Adobe block construction relies on a hot, dry climate. The inspiration for my project was to explore how this type of construction could be done successfully in the wet, temperate climate of the Northeastern United States. Following are three building solutions that are low-cost and environmentally responsible.

My first case study of alternative construction involves rammed earth. My experience in Mexico spiked my interest in earth construction techniques. With Root Studio I was able to witness and be a part of this type of low-cost, sustainable construction. Rammed earth construction is very similar to adobe construction, but, because of the qualities of the earthen mixture and the actual methods of building, it is more suitable to a Northern climate. In the following section I will present my research on the viability of insulated rammed earth construction in a cold, wet climate.

I was drawn to recycled wood as my second design solution because of the vast of amount of reclaimed lumber that is currently available in this part of the country. In the nineteenth and twentieth centuries, the vast majority of houses and barns were built out of wood that was harvested from old growth forests. This wood is inherently much stronger than the wood that we build with today which is harvested from much younger trees.

Many of these homes and barns are still standing or need to be torn down leaving a plentiful source of recycled wood that we can reuse to build new homes today.

My third case study is eco-friendly modular construction. Advancements in technology have made modular home construction more environmentally sustainable, more affordable, and more beautiful. This is a very important option to explore for high quality housing when time is an issue, as modular construction takes a third less time than on site construction. Modular construction is less labor intensive compared with the two previous building options. It often involves materials that require little maintenance, a very important factor for low income families who do not have the time or money for maintenance and improvements.

Rammed Earth for a Cold, Wet Climate

A new look at the oldest and most widely used building material on earth

Traditionally, rammed earth structures have been built in dry, semi-arid to arid climates. Today, we are globally seeing a demand for both low-cost and sustainable residential architecture and so it is important to analyze the viability of rammed earth construction in regions of varying climatic types.

Rammed earth is similar to adobe block construction in that the main material in its composition is earth. Unlike adobe buildings, which are built with a brick-like formation of layered adobe blocks, a rammed earth structure is built by tightly compacting layers of an earthen mixture between rigid wooden frames, and then removing the frames once the earth is sufficiently packed down. Like adobe construction, the building materials ideally are collected entirely from the construction site, making the building method an environmentally-sustainable and cost-effective technique.

The rammed earth process begins with soil selection. To give cohesion, stability and strength to a wall there must be an appropriate ratio of sand, gravel and clay in the earthen material.[4] Ideally, the ratio consists of :

15-18% clay
23% coarse aggregate
30% sand
32% silt.

These materials are compacted with special tools to create walls that are durable, low-cost, completely sustainable and, if properly maintained, can last for many centuries.

Figure 2: Adobe

Figure 3: Rammed Earth

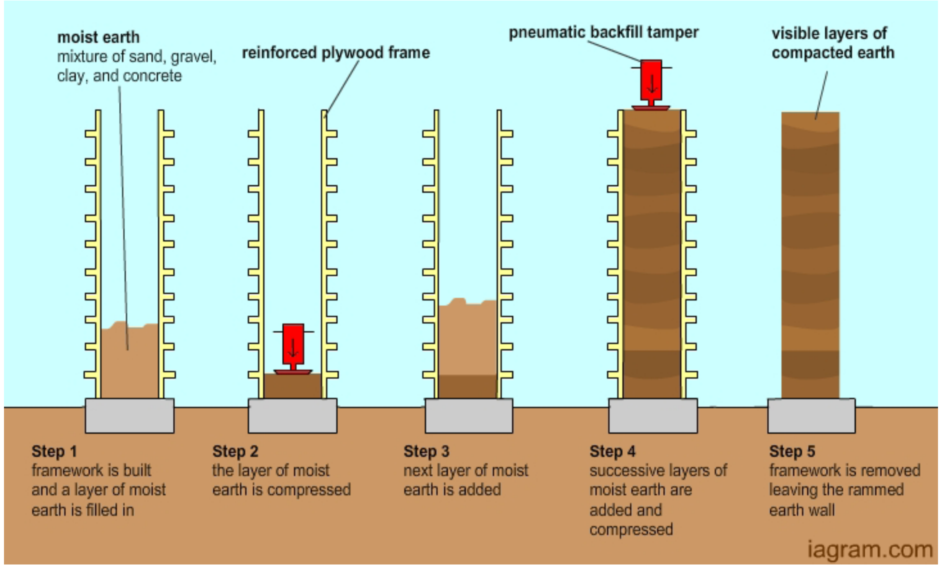


Figure 4 : Rammed earth construction process

Environmental and Economic Advantages

Rammed earth construction is inherently sustainable and affordable because the building is made from natural materials gathered on site. Walls can be constructed from the earth dug for the foundation of a building. This reduces a considerable amount of pollution from mining or deforestation that would be necessary with other types of construction, and also reduces the environmental and economic cost of transporting materials to the site. Structures made from rammed earth are highly recyclable. Earthen buildings can be abandoned and their ruins will simply melt back into the ground from where they were dug. Remains can be used to grow vegetation or be re-used again as a building material.[5]

Figure 5: A modern rammed earth house in Wyoming

Analysis of Rammed Earth in a Cold Climate

To analyze the viability of rammed earth as a building envelope in a cold, wet climate such as Connecticut, there are numerous factors that need to be considered. These factors include the design's ability to resist thermal losses, to prevent air infiltration, to provide a high indoor air quality, to control moisture condensation and infiltration, and the availability of local materials, all under that specific climate environment.[6]

Thermal mass

A dual economic and environmental benefit of rammed earth is its excellent thermal mass properties. Thermal mass is the ability to absorb heat during warm periods and release it over cooler periods that follow. With such high thermal mass, rammed earth buildings can maintain comfortable interior temperatures without the need for heating and cooling, in the process saving money and reducing dependence on fossil fuels.[7]

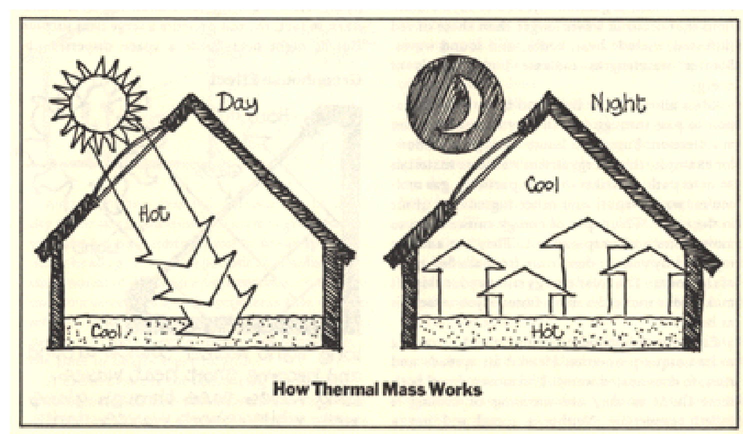


Figure 6

Moisture control

In this climate, rammed earth structures, just like any other masonry building, need both a proper concrete foundation that extends below the freeze line, and some sort of exterior coating to protect from rain and snow. As for the latter issue, the effect of precipitation falling upon rammed earth is not as damaging as one might think. In 1926, the U.S. Department of Agriculture released a publication titled "Rammed Earth Walls for Buildings" discussing the viability of rammed earth to withstand in differing climates. This publication recommends some form of exterior finishing for rammed earth walls, but also provides examples of rammed earth structures that have withstood many winters in England with no protection.[8] The USDA recommends "a liquid waterproofing mixture, such as a solution of silicate of soda, a lime wash made with boiling water, hot coal tar or a solution of bitumen, resin or paraffin in light oils."[9] This finishing will increase compressive strength and water resistance, and reduce the soil's expansion due to ambient moisture or precipitation.[10] The capability of rammed earth to withstand rainfall can be increased by adding a larger clay ratio to the mixture, and with proper roof overhangs.

Figure 7: Foundation below freeze line

Insulation

Just as with any other building material in this climate, rammed earth structures in this part of the country would need to be insulated to obtain the proper thermal retention rate or R-value. This combination of rammed earth and insulation incorporates low thermal conductivity and high thermal mass. Having low thermal conductivity (high thermal resistance) means that in the winter, cold temperatures cannot permeate the interior of the house, giving the structure thermal insulation. A material that has high thermal mass means that it has the ability for the walls to absorb heat and release heat. The combination of these two properties, and these two materials, makes rammed earth a viable option for cold climates.[11]

In British Columbia, SIREWALL (stabilized insulated rammed earth wall) has developed an insulated rammed earth wall that is suitable to the cold, wet climate of western Canada. In this system, a rammed earth wall is typically 18" to 24" thick, stabilized with compacted earth and rebar, and with 4" of rigid insulation hidden in the center of the wall.[12] The company generally uses a polyisocyanurate foam as the insulation material in the core of the wall. The SIREWALL system achieves an R-value of R-33 and higher and their walls are resistant to 2,500 pounds per square inch of pressure washer.[13] On the following page is a diagram from the SIREWALL system website detailing the makeup of this method of construction including insulation and foundation.

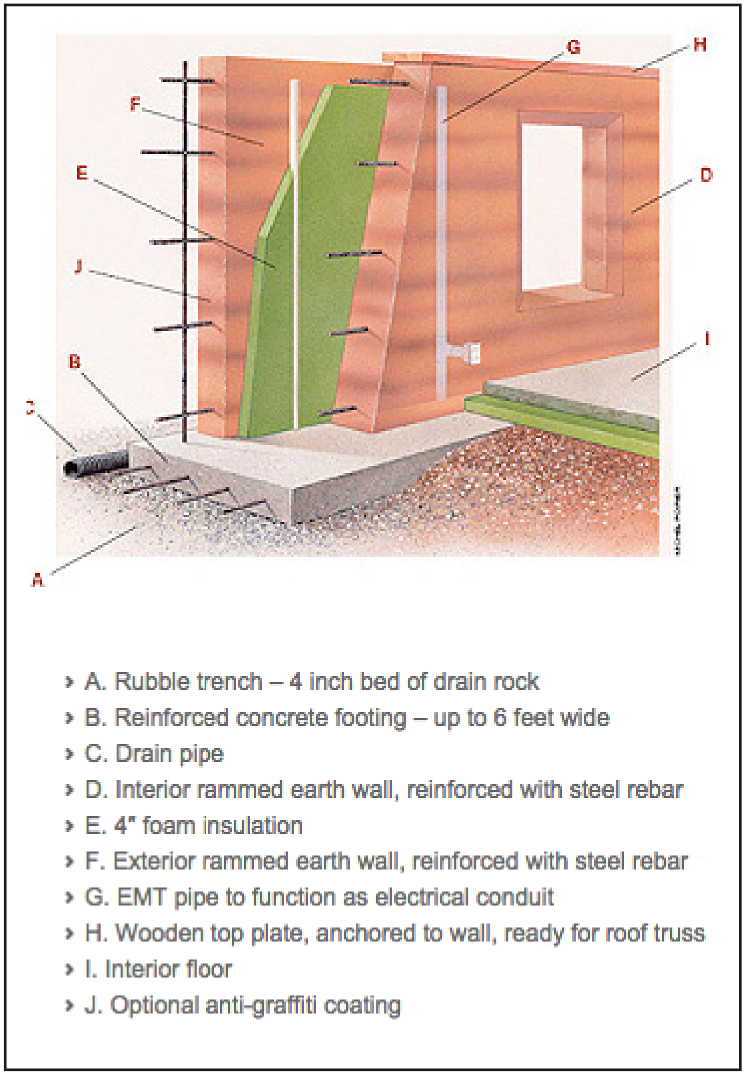


Figure 8

SIREWALL has been building rammed earth residential and commercial structures in the cold, wet climate of British Columbia for over twenty years. In the following section I present two examples of rammed earth structures built in the similar climate of New England.

Joe Dahmen, MIT

Before building his wall in the summer of 2005, Dahmen conducted extensive research to determine if local New England soil would be appropriate for rammed earth construction. Dahmen concluded that the best option was to use a combination of marine clay, a type of clay found in coastal regions, mixed with commercially available, locally produced sand and gravel.[14] The wall is protected from rain and snow by a steel cap on top of the wall.

Figure 9

Figure 10

Figure 11

Rammed earth home in Salisbury Cove, ME

Another example of successful rammed earth construction is Susan Turner and Karl Karnacky's rammed earth home in Salisbury Cove, ME. The couple built their home on the coast of Maine after years of research. Like Dahmen's project at MIT, the rammed earth composition used to build this house was high in marine clay content. About one-third of the soil excavated for the house's foundation was reused for construction and the rest was composed with local soil. For insulation, the couple employed the SIREWALL construction system (see Figure 8), which places the 4" of foam insulation between two sections of rammed earth wall. This type of construction is visible in the previous image (Figure 11).

Figure 12

Building with Reclaimed Lumber

And other recycled materials

To build in a more environmentally responsible way that costs less, it is imperative to explore building with recycled materials. In any structure that is ready to be dismantled, many or most of the materials can be salvaged and reused in a new home construction project. This environmentally friendly process is called "deconstruction" in contrast to demolition which send tons of debris to landfills.[15] With deconstruction, a building is taken apart in a way so that every component of the building that can be reused, re-purposed or recycled. The process of recycling is inherently sustainable because it both reduces the amount of resources necessary to produce new building materials, and re-using these already-made materials means we can produce less waste. It is especially important to recycle lumber. The EPA estimates that more than a billion board feet of lumber is simply thrown away each year.[16] Apart from the environmental and economic advantages to building with reclaimed lumber, this type of old-growth wood is often more structurally sound compared with lumber on the market today.

Old growth forests have been over-logged for centuries and there are very few of these old forests left. Conservation efforts offer the solution of "managing" forests, the outcome of which is forests full of "new growth" trees. Today, the lumber that we build with is usually logged from these relatively young forests. The difference in density and stability of a new growth tree compared to an old growth tree is large. Over time, trees have to withstand the forces of nature - strong winds, inclement weather, shifting terrain - all of these factors make a tree stronger. Because there was less carbon dioxide in the atmosphere when old-growth trees were planted, the trees grew much more slowly. That slow growth created a dense cellular structure and is why many old growth barn timbers have held up for hundreds of years.[17]

Figure 13

Building with salvaged materials costs between 10 and 50 percent less than buying comparable new materials.[18] In some cases, the owner of an dilapidated building will allow people to simply take whatever they can safely remove. This makes the take-down process a little easier for the owner, with less material to deal with, and the person salvaging receives the materials that cost nothing more than time and labor. This process of finding and re-using, like rammed earth construction, is more time-intensive that building with store-bought, new materials, its takes research and planning, but the outcomes are well worth the added time and consideration that goes into a building.

Wood is the most commonly salvaged material because it is so ubiquitous in both old and new construction. Wood can be salvaged from all different areas of a building: siding, structural timbers, existing wood flooring, interior paneling, doors, etc.[19] Reclaimed lumber, depending on its makeup can be used as both a structural and non-structural building material. The best reclaimed portions to use as structural support are old timbers and beams. These pieces of wood they are so inherently sturdy and sound because when there were first employed, they were harvested from the strongest among a forest of the old-growth trees. As such, reclaimed timber often exceeds the structural qualities necessary to meet local building codes because codes now are based on much younger and less sturdy trees.

However, not all reclaimed timbers can be grade-stamped at their original grade level due to bolt holes or other conditions. An architect or structural engineer should perform load and bearing calculations before beginning construction.

The most affordable method of salvaging materials is to find an abandoned building (or part of a building that is being redone or renovated) and an owner who is willing to have materials salvaged at no cost. This option is the most labor intensive and requires following proper safety precautions. The second best option, which is much less labor intensive, is to find a local retail or wholesale salvage company. There are numerous reclaimed lumber companies here in Connecticut, such as Armster Reclaimed Lumber in Guilford, CT or Connecticut River Lumber Co., in Old Saybrook, CT.

Building with reclaimed lumber entails doing research, and such, any homebuilder should look at the amount of prep work that would be required to make the material project ready. If the wood is being salvaged from an abandoned building, it is important to first know the history of that building. Unfinished wood in an early twentieth century factory may have been exposed to high levels of toxic chemicals. Before using any material it is critical to check for structural integrity and any obvious signs of damage.

The Backyard House

In building the Backyard House in Portland, OR, the architect Morgan Lea was inspired by Bernard Maybeck's 1931 "Mistake House" at Principia College in Elsah, Illinois[20] which was built with multiple, varying materials to display the different types of construction used in building the College. The Backyard House has a similar function. It is both a small house and a display of how building with reclaimed lumber is both a sustainable and affordable method of construction. The wood for the house was donated by three local barns in Oregon and the copper roof was found by the architect on craigslist.

Figure 14

Figure 15

Eco-friendly Prefabricated Construction

Prefabrication: background and today
Prefabricated construction involves the transportation of building parts manufactured in a factory to a site where they can be assembled into a finished building. There are examples of this type of construction in America as early as the early English settlement in Cape Ann, MA, where they made panelized fishing sheds in 1624.[21] The real increase in this type of building came with the Industrial Revolution, as industrialized, mass-produced materials typically lend themselves to prefab construction. Elements such as cast iron, structural steel, large sheets of glass can be manufactured off site, and then easily assembled on site. Between 1908 and 1940, catalog giant Sears Roebuck and Company sold more than 100,000 prefab home kits to Americans.[22]

MODERN HOME No. 147

This house has been built at Kankakee, Ill., Great Bend, Kan., St. Louis, Mo., Mandan, N. Dak., and East Falls Church, Va.

COULD NOT WISH BETTER MATERIAL.

Mandan, N. Dak.

Sears, Roebuck and Co., Chicago, Ill.

Gentlemen:—The material furnished for Modern Home No. 147 was fine and I could not wish better. **I saved about $225.00** after paying freight. Very truly yours,

ARTHUR WITHEROW.

—30—

$872.00

For $872.00 we will furnish all the material to build this Six-Room Bungalow, consisting of Mill Work, Siding, Flooring, Ceiling, Finishing Lumber, Building Paper, Pipe, Gutter, Sash Weights, Hardware, Painting Material, Lumber, Lath and Shingles. NO EXTRAS, as we guarantee enough material at the above price to build this house according to our plans.

By allowing a fair price for labor, cement, brick and plaster, which we do not furnish, this house can be built for about $1,530.00, including all material and labor.

For Our Offer of Free Plans See Page 3.

AN ATTRACTIVE cottage of frame construction and a popular design. The front elevation suggests the bungalow type of architecture. It has a large porch, 8 feet wide, extending across the front of the house which is sheltered by the projection of the upper story and supported with massive built-up square columns. Unique triple window in the attic and fancy leaded art glass windows add much to this pleasing design.

Main Floor.

From the front vestibule, which is 4x5 feet, you enter a large living room, 11 feet 6 inches by 14 feet. This room has a nook, 7x5 feet, with cased opening which can be used as a reading room or library. Living room leads directly into the dining room, back of which is a good size kitchen, 11 feet by 10 feet 10 inches, with combination cupboard which opens from both dining room and kitchen, a very convenient arrangement. This cupboard has four china closet doors glazed with leaded crystal glass facing the dining room. The kitchen side of the cupboard has six paneled cupboard doors and four small doors above. A double swinging door leads from the dining room to the kitchen. We furnish plate rail for the dining room. Note the arrangement of the two bedrooms, one in the front and one in the rear, the idea being to provide as much light and ventilation as possible. The front door is made of veneered birch, 1¾ inches thick, glazed with leaded art glass. All inside doors two-panel birch, with clear birch trim such as casing, baseboards, molding, etc., to match. All floors are made of clear yellow pine flooring laid on sub floor. Framing timbers are all No. 1 yellow pine. All rooms are 9 feet from floor to ceiling.

Basement.

The basement under the entire house has a cement floor and is 7 feet from floor to joists. Built on a concrete block foundation.

All outside walls covered with 1-inch dressed and matched sheathing boards lined with heavy building paper and sided with clear cypress bevel siding to the first story and "A" cedar shingles above first story line and on to the roof.

Paint for two coats best paint on the outside. Varnish and wood filler for two coats for interior finish.

This house can be built on a lot 27 feet wide.

Complete Warm Air Heating Plant, for soft coal, extra	$ 55.30
Complete Warm Air Heating Plant, for hard coal, extra	58.56
Complete Steam Heating Plant, extra	118.40
Complete Hot Water Heating Plant, extra	152.13
Complete Plumbing Outfit, extra	116.93
Acetylene Lighting Plant, extra	47.90

SEARS, ROEBUCK AND CO. — QUALITY GUARANTEED — CHICAGO, ILLINOIS

Figure 16

After WWII, the government subsidized prefabricated housing. It was quick and economical in a time of increased housing demand in the U.S. However, as time passed, people began to associate prefab housing with cheap, inferior quality housing and bad design.[23]

Today, with so many people severely burdened by their housing costs we have a similar need for affordable housing. And with the increased impact that humans and housing place on the natural environment, that affordable housing needs to be environmentally conscious as well. Eco-friendly prefab "explores the intersection of sustainable design, affordable housing and prefabricated construction".[24] It involves the creation of prefabricated homes that are regionally-specific, use natural ventilation and lighting and are built with sustainable and locally-sourced materials in a factory setting and then transported to site.

Modular Technology
The process of off-site modular construction is inherently sustainable. There is less energy consumed because workers are not traveling to the site and from the site for the duration of the construction process. With modular construction, building materials can be used more completely, and more efficiently, producing less waste. Building in a factory allows for precision cutting, so each cut is done right the first time. Modular home construction achieves 50 to 70 percent less waste compared with on site-construction.[25] The finished modular product is more tightly constructed and thus more energy-efficient than a site-built home.

As manufacturing technology has advanced, residential design has pursued more complex prefab components. Today, complete homes or engineered modules can be built off-site in a climate controlled factory environment, and then transported on trucks, ferries or trains to a building site, where they are set onto a site-built foundation.[26] This method of construction is much more time-efficient than regular on site construction. When Michelle Kaufmann, author of *PreFab Green*, and her husband decided to build their modular home they did a comparison between the two building types - between off site and on site construction. They found that the off site home not only took significantly less time to build, but they were also able to build their home at a cost of 15 percent less than a site-built house.[27]

Customization and Construction
In the prefabrication process, customization can happen at many levels. This individuality starts with the floor plan and also includes roof type and materials used. A modular home is constructed from the inside out. This technique, in a factory, allows many people to work on different aspects of the house at the same time, including inspectors to review each step of the home building process to ensure the highest quality.

The most affordable prefabricated construction technique is to build with Structurally Insulated Panels (SIP'S). SIP's are a high performance building system for residential and light commercial construction. The panels consist of an insulating foam core (EPS) sandwiched between two structural facings, typically oriented strand board (OSB). SIP's are manufactured under factory controlled conditions, reducing waste at the construction site.[51]

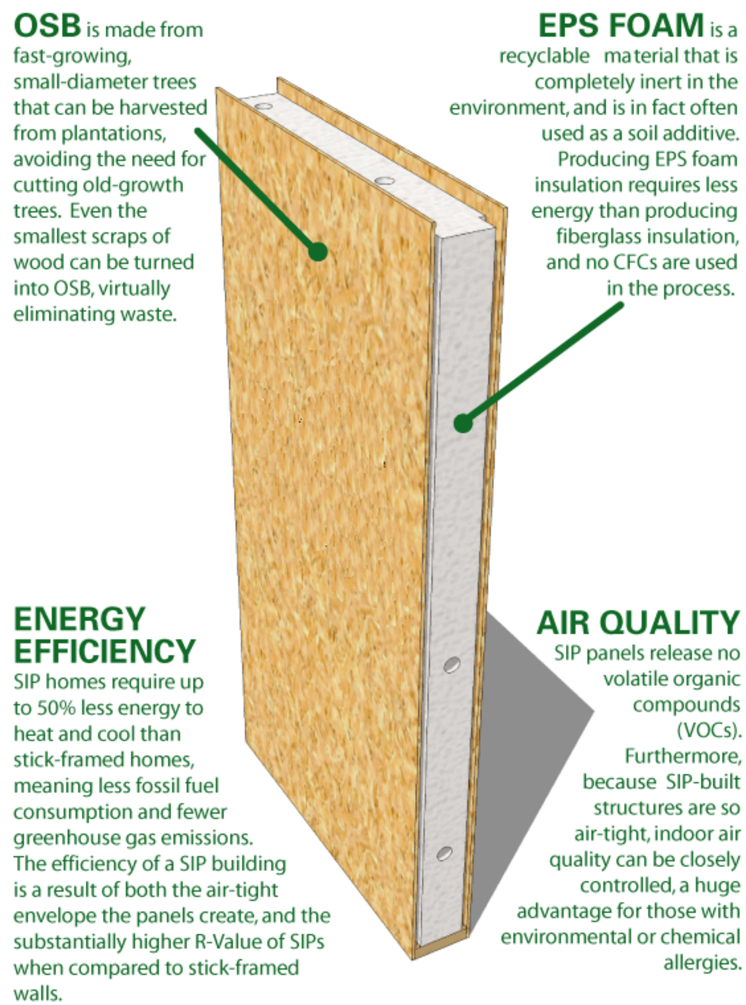


Figure 17

Building with SIP's generally costs about the same as building with wood frame construction when you factor in the labor savings resulting from shorter construction time and less job-site waste. Other savings are realized because smaller heating and cooling systems are required with SIP construction."[28] Ensuring that prefabricated, modular housing has potential as a low-cost and environmentally-responsible building method entails rethinking the materials used. There are many prefabrication companies in Connecticut who pride themselves on being environmentally responsible and would be open to incorporating sustainable elements like SIP's and reclaimed lumber into their modular homes.

Prefab homes as the way of the future

Prefabrication and modular technology offers an educational opportunity. Alastair Parvin developed WikiHouse, an open-source construction system. His system contradicts the age-old trend in architecture that is to design for about the richest one percent of the world's population. Parvin's idea behind WikiHouse is to switch that model from the one percent to the 100 percent. He offers a solution to this problem through the democratization of production, an idea inherent in communist and socialist theories. To make production democratic, Parvin come up with the idea of open source software and open source hardware, which are freely shared blueprints of houses that anyone can download and make for themselves. In Parvin's words:

> What these technologies are doing is radically lowering the thresholds of time and cost and skill. They're challenging the idea that if you want something to be affordable it's got to be one-size-fits-all. And they're distributing massively really complex manufacturing capabilities. We're moving into this future where the factory is everywhere, and increasingly that means that the design team is everyone. That really is an industrial revolution. And when we think that the major ideological conflicts that we inherited were all based around this question of who should control the means of production, and these technologies are coming back with a solution: actually, maybe no one. All of us.[29]

His idea is to make it possible for anyone to go online and access a free shared library of 3D models of houses, that can be printed out in modular sections using a CNC machine which cuts plywood into predetermined shapes. All the parts are numbered and can be put together using wedge and peg connections rather than using bolts. In Parvin's model, a team of two or three people can build a small house in about a day without any traditional construction skills, and without a huge array of power tools. This is truly the model of affordable and sustainable construction of the future, one that is available to anyone.

Local Focus: Habitat for Humanity Co-housing Community

Norwich, CT

Associated with each of the design solutions that I have researched is a re-conception of traditional housing construction. We need to reconsider the materials with which we build our homes, and the scale at which we build them. A truly sustainable design is not one that is out of reach of the average citizen. Sustainable design needs to be affordable, use less resources and less space.

To give my research a local design focus, I worked with the Eastern CT chapter of Habitat for Humanity to create a design for a co-housing community that will be built in Norwich, CT.

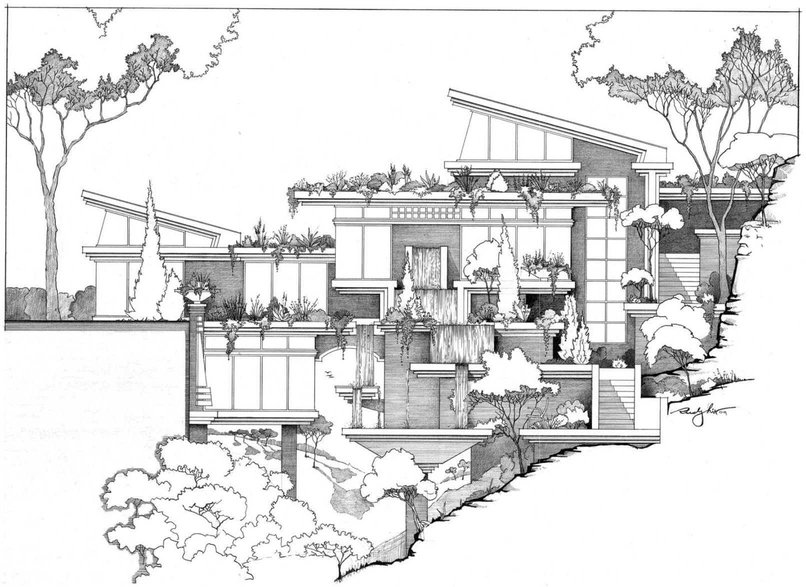
My design evolved over the course of the semester in consideration of the site, of the desired size of the community, and in attempt to choose the most sustainable building materials, environmentally and economically. My proposal for this 8 home community explores the option of using reclaimed lumber for the exterior siding of my houses, and SIP's as the framework construction method. For structures built with reclaimed lumber this type of factory-based, modular construction makes the most sense because many of the reclaimed pieces of wood need to be re-cut to fit specific needs, and this is more easily done indoors in a factory, rather than onsite. Prefabrication makes a lot of sense environmentally and economically, but especially in terms of multi-family housing designs such as the community of homes in Norwich.

Habitat for Humanity families often work full time and as such, the materials used in their homes must be long-lasting and low maintenance, as they do not have the time or the money for upkeep of materials. My design employs SIP construction with metal roofing. Compared with other types of roofing, metal roofs are low-cost and sustainable. Metal roofing is protected by highly durable paints and coating, ensuring a lifetime of 40 years of more and protection against severe weather. Metal roofing contains 25-95% recycled materials and is virtually 100% recyclable. Metal is also very energy efficient. ENERGY STAR-labeled metal helps lower heating and cooling costs.[30]

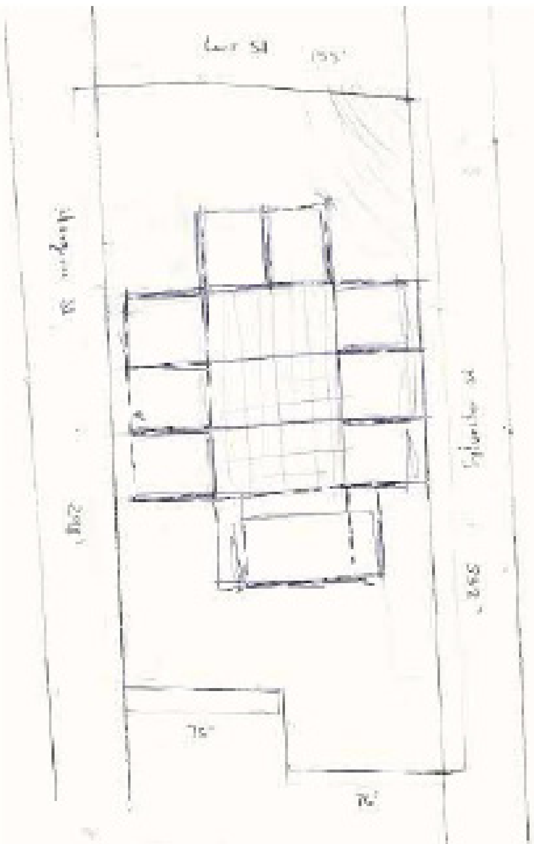
In my design, many of the dwellings are attached, meaning that total material and land usage can be reduced, and many energy systems can be shared. The eight acre site has space left over to leave as a central, shared courtyard.

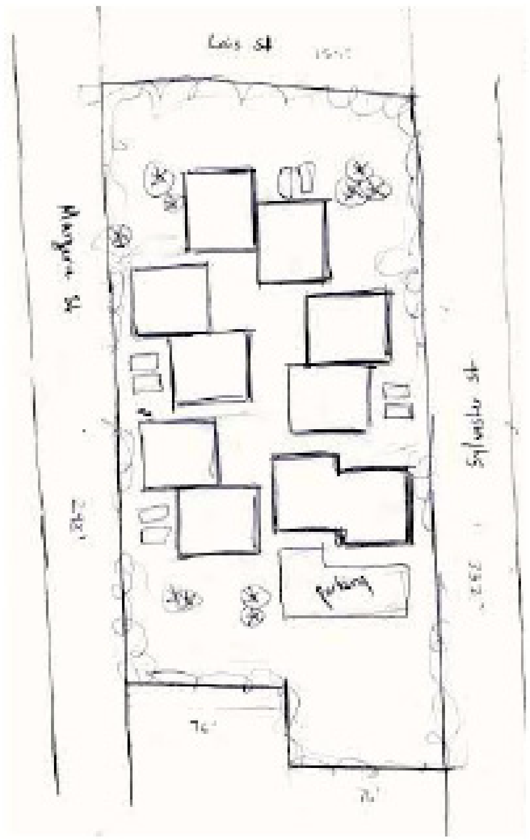
Jystrup Savværk co-housing community, Denmark

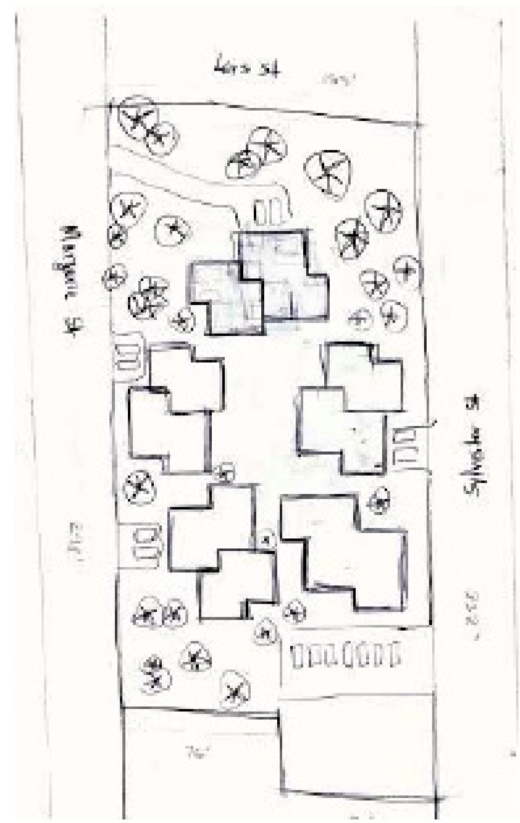
Galgebakken community, Denmark



Koinania Farm

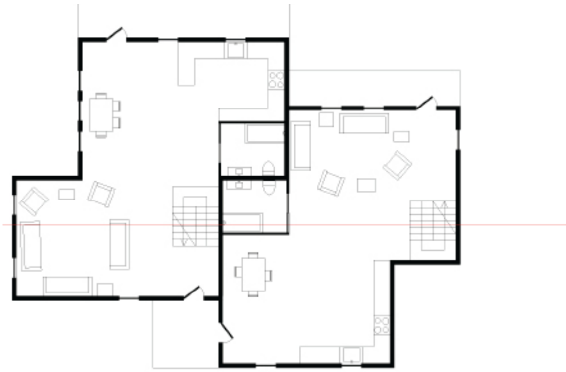

Lois St
Sylvester St
76'


Lois St
Morgan St
Sylvester St
parking
76'


Lois St
Morgan St
Sylvester St
76'

Concept Drawing

Final Design



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Images:

Figure 1: OIDHO, Atzompa, OAX, Mexico. 7 July 2014. Personal photograph by author. JPEG file.

Figure 2: San Juan Mixtapec, OAX, Mexico. 20 June 2014. Personal photograph by author. JPEG file.

Figure 3: “Insulated Rammed Earth: What Is SIREWALL?” SIREWALL.com. Web. 15 Jan. 2015.

Figure 4: “Rammed Earth Construction.” Weblog post. Engeye: Design Build. N.p., 13 Sept. 2010. Web. 23 Nov. 2014. <https://engeyedesignteam.wordpress.com/>.

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Figure 8: “Insulated Rammed Earth: What Is SIREWALL?” SIREWALL.com. Web. 15 Jan. 2015.

Figure 9: *Ibid.*

Figure 10: *Ibid.*

Figure 11: Salisbury Cove, ME. 7 October 2012. Personal photograph by Susan Turner. JPEG file.

Figure 12: Salisbury Cove, ME. 12 March 2013. Personal photograph by Susan Turner. JPEG file.

Figure 13: “Guilford Barn.” Historic Barns of Connecticut. CT Trust for Historic Preservation, Web. 20 Dec. 2014.

Figure 14: “The Mistake House (1931).” Maybeck and Principia College. Principia College, Web. 14 Nov. 2014.

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Figure 18: “Metal Roofing Connecticut.” Metal Roofing Connecticut. Web. 14 Jan. 2015. <http://www.metalroofconnecticut.com/>.