A Prefabricated Framing and Enclosure System: Economy, Flexibility, and Applications

John Hilgeman

A thesis submitted in partial fulfillment of the
requirements for the degree of

Master of Architecture

University of Washington

2004

Program Authorized to Offer Degree:
Department of Architecture

University of Washington
Graduate School

This is to certify that I have examined this copy of a master's thesis by

John Hilgeman

and have found that it is complete and satisfactory in all respects,
and that any and all revisions required by the final
examining committee have been made.

Committee Members:

Dean Heerwagen

Mark Gross

Scott Carr

Date: ____________________________

TABLE OF CONTENTS

LIST OF FIGURES

Figure Number Page

LIST OF TABLES

Table Number Page

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Dean Heerwagen for volunteering his time and extensive knowledge of all types of systems. I would also like to give my deepest gratitude to Mark Gross for expressing interest in my thesis and guiding me to a clarified and critical understanding of my own goals. In addition, Scot Carr and Dave Miller were instrumental in helping me evaluate the design in architectural terms.

PREFACE

I initially became interested in building systems soon after my introduction to architecture. I observed that in any well designed building, there are a number of systems that work together. These systems include circulation, mechanical, electrical, spatial, and structural. Some buildings, I found, used systems in a manner that frustrated me, either by ignoring one in order to emphasize another or using traditional design methods for new materials and products. For example, I observed that in many buildings, structural systems are buried beneath and behind finishes and cladding. Mechanical and electrical systems are forced into leftover spaces and hidden behind finishes. It seems that spatial systems often take precedent and are completely isolated from other systems. These spatial systems become singular compositional moves that force other necessary systems into places and conditions that are inappropriate for their uses. This building system was inspired by my own desire to remedy some of these problems in affordable construction.

INTRODUCTION

In the realm of construction types there are two very polar conditions. One condition is that of complete customization, where every material, space, and connection are designed specifically for the structure at hand. The opposing condition is that of complete standardization where every material, space, and connection are literally or conceptually prefabricated and designed without regard to any particular project or site need.

I have developed a system which is intended to find a balance between these opposing conditions. In order to do this (allowing certain elements of the system to be custom, others to remain flexible, and others to be standardized) I had to make decisions regarding the nature of different building components and the groups to which they belong. Some parts could be completely standardized while others could be left custom in order to accommodate the tastes and preferences of different users.

In the system I have developed, the parts that are left completely custom are those that possess a tactile quality in the everyday experience of the inhabitants. Specifically, I have not standardized openings such as doors or windows, finishes, partition walls, and mechanical/electrical systems.

It is simple to explain the sensory qualities of doors, windows, and finishes, whereas mechanical/electrical systems tend to have a removed physical presence from the mainstream activity of daily life. However, these systems produce some of the most tactile and elemental features in the built environment - light, water, and heat. Due to the huge variety of systems for heating and distributing water and air, and the immense array of lighting and electrical possibilities, I have allowed these systems to remain custom. In essence, the most intimate features of the building may be personalized and given a character of their own.

Some parts of a construction system require a degree of flexibility but do not need to be completely customized. Specifically, these are enclosure walls and exterior cladding. Space defining enclosure walls need the flexibility to move around for different designs and programs. However, they do not need the same personalization as a window sill or door knob. Cladding needs very little personalization but must be able to respond in some way to existing context and the exterior aesthetic preference of the owner. The enclosure walls and cladding are standardized but interchangeable in a way that allows a fair amount of design flexibility.

Of all the building parts, the structure is the most removed from the intimate details of daily life. It is the quiet giant that supports the lives and settings we create within it. The structure in this system is completely standardized.

A BRIEF HISTORY OF PREFABRICATION

The concept of prefabrication is born out of logic and predates industry by thousands of years. It finds roots in hunting, warfare, art, construction, and many other activities that are intrinsically linked to the existence and survival of *homo sapiens*. Prefabrication originally took the basic form of developing systems, either conceptual or actual, that led to the production of parts that could be used in a variety of ways. Eventually, prefabrication became necessary for meeting the demand for products, food, and entertainment of the growing masses. Early examples would be the specialized production of forks, glassware, horse shoes, and arrows.

In the period when architecture was becoming a major form of cultural expression, prefabrication found a conceptual role in the hands of Andrea Palladio. Palladio found himself inundated with commissions for palaces and villas, and decided early in his career that standard optimal forms, such as column proportions and stair arrangements, were desirable. His work was founded on a set of conceptually prefabricated building elements. This allowed him to handle the work load as well as provide a variety of creative alternatives to a single design.

Soon after a revival of interest in classical architecture, the architect Jean-Nicholas-Louis Durand published a book called *Lessons of Architecture*, in which he set out rules and a systematic grammar for the development of architectural designs. Durand was a student of the neoclassical theorist and architect Etienne-Louis Boullee. Boullee and Durand parted on the critical issue of the purpose of architecture. Durand felt that the aim of architecture was, rather than aesthetic, the welfare of the users and an architect's greatest organizer for composition was the floor plan. In the vane of prefabrication, Durand sought to rationalize the architectural process.

Starting in the early 18th century, The Industrial Revolution had an immeasurable influence on architecture and prefabrication. All design was affected by the common use of new materials such as steel and glass. Design changes were fundamental in some cases and gave rise to new styles whose roots were solidly planted in the concept of industry. Later, in the 20th century, this style found a voice in the work of the European modernists Le Corbusier, Gropius, Mies van der Rohe, Alvar Aalto, and JJP Oud.

The post WWI era in Europe saw a major increase in the industrialization of building. Due to the destruction of existing buildings and the lack of new construction during the intra-war years, there was an acute demand for economical and simple building systems. Housing saw the greatest progress in prefabrication as architects began to more widely accept the use of standard parts, steel, and glass. One issue with many of the building systems developed during this time was that flexibility was not part of the overall design. These systems did not provide room for a creative response to an architectural problem.

At this point in history, prefabrication found a niche in a world that needed to deal with an increasing number of new technologies. For example, the Orly Airship Hangars outside of Paris were made of prefabricated concrete arches whose repetitive use and high volume of enclosure allowed for the storage of such massive units as blimps.

This period also saw the founding of the Bauhaus, a haven for the international style. This school was founded by Walter Gropius in 1919 and became a place where he spread and taught his beliefs concerning the need for new design to be based on mass production. Stark white walls, industrialized parts, and machined details became the hallmark of this style.

World War II was concluded with another housing crisis both in the United States and Europe. Though United States territories had not seen any action, there was a need for housing due to the number of returning soldiers who quickly started families. A population explosion accompanied the end of the war. Once again, prefabrication was used to meet the demand for housing. Entire communities, such as the one in Levittown, NY (Fig. 1), appeared with row after row of prefabricated, largely identical houses. Thus, the “mushroom farms” were born.

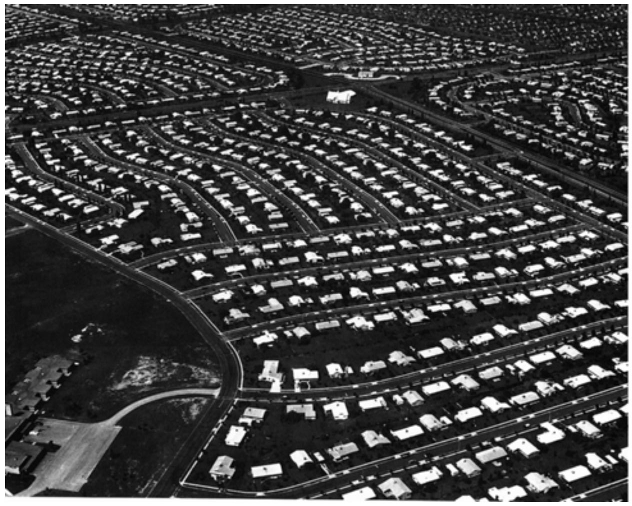


Figure 1. Levittown prefabricated homes (teachpol.tcnj.edu/amer_pol_hist/ fi/000001ad.htm)

In the 1960's, there was a more theoretical exploration of industrialized building systems. Much of this research took place in Europe, but never caught on as a mainstream idea. Part of the reason for this was the relatively slow housing market at that time in many European countries. Other countries, however, had a great demand for housing, and industry promised low cost success in solving the problem. As usual, the presence of a market drove the development of industrialized housing in those countries. However, this development was driven by profit and lacked any aesthetic attention other than what was afforded to it in order to create market value. As a result, manufactured housing took the form of commonly accepted traditional styles such as the gable roofed colonial. In the worlds two largest housing markets, the United States and Japan, there are extensive examples of this reality.

A typical suburban street in Japan includes a number of traditional western style houses that are almost identical, each delivered direct from the factory. Prefabrication in Japan has advanced to the stage where manufacturing, ordering, stock, and delivery are almost completely automated. Sekisui, the largest prefab company in Japan has automated warehouses where parts are produced, stored and shipped by robotic arms that move on tracks. Although nowhere near Japan in production technology, the United States builds almost 20% of the new houses via prefabricated processes. This is not to mention the innumerable new construction projects that use prefabricated parts such as roof trusses and wooden I-beams. Virtually every new project in the United States has some prefabricated element to it.

There are a number of reasons for the success of industrialized housing in these two countries, the first of which is the demand. Other factors are the benefits that come with factory manufacturing such as energy efficiency, speed of erection, and low cost. This is why many customers choose industrialized housing over conventional construction.

Unfortunately, the result of the proliferation of a purely profit based attitude is the creation of an unfortunate environment where once beautiful and innovative designs are stamped out like cars off an assembly line. The style from which these designs are taken is no longer alive in this type of construction. These houses now represent a human refusal to let go of the past at the cost of compositional styles that were at one time beautifully and carefully constructed. My system is intentionally expressive of its own construction and logic in an attempt to state the real processes and ideas that are involved in the creation of a modern building.

European examples of industrialized building systems from the 1960's celebrated the potential of the factory and embraced styles that expressed the mechanical nature of modern buildings. They also sought to explore the implications that industry would have on existing architectural styles.

Specifically, the Jesperson system of industrialized building includes a frame made of precast concrete wall panels. These panels bear the load of pre-cast floor and roof slabs. The rules of the system follow a planning module which includes cross wall paneling in every other bay. The modules are four feet deep by a minimum of one foot wide. The maximum width is eighteen feet. The cross wall panels are placed for the purpose of handling wind loads. Aside from these constraints, the designer may use any form of external infill or cladding.

The cladding may also become standardized for the sake of costs. Interior floor finishes in this system are often vinyl on the first floor and timber boarding across battens on the upper floors. The wood on the upper floors is in response to the unpredictable nature of the finish on concrete floor panels, whereas the ground slab is much more controlled.

Figure 2 - A Completed Jespersen System (Diprose, 1966)

The Jespersen wall has a butt joint between panels which can be finished to obtain a flat surface. Internal partitions are faced with plasterboard. These partitions are brought to the site finished and assembled in panels. The openings for doors and window have pre-drilled screw holes to allow for easy installation. The partitioning system is not considered to be demountable.

The Jespersen system does not favor the use of electric lighting on the ceiling, but rather in the spaces between the plasterboard wall panels. The panel itself, being hollow, will also accept lighting fixtures. Wiring to the partitions is placed either in a recessed timber skirting or in the space between battens under the floor.

Another system that became well known in the 60's and whose ideas are still applicable today is the 5M system. The essential criterion in the design of the 5M system was flexibility of layouts and capability for application by local architects and builders. The frame consists of steel stanchions with plywood box beams on the perimeter and timber beams internally (Fig). The system itself is based on a twenty inch grid and standardized components are all based on the carrying capacity of two men.

The 5M System itself has not been hugely successful, although some of its components and ideas have become standard in industrialized building. The most successful component was what became known as the "5M party wall". This wall is constructed of two skins of plasterboard sandwiching a fiber glass curtain.

Finally, the Belfry system demonstrates a design that allows for ventilation of structure and provides flexibility in the use of mechanical systems and interior design. The system is based on pre-cast concrete cross walls which support load bearing beams at the center and perimeter. The beams carry floor slabs, roof slabs, and external cladding. The internal planning depth of a given unit is twenty seven feet and the width, or distance between cross walls, may be anywhere from sixteen feet to thirty six feet.

Figure 3 - A completed Belfry system (Diprose, 1966)

The load bearing perimeter beam has a depth limited to twelve inches, so any spans greater than twelve feet include intermediate support from a structural concrete panel. This panel becomes part of the structural expression on the façade. Infill is made of timber framed panels which may house windows and doors, and include timber weatherboard cladding.

The roof of the system is a waterproof concrete slab which requires no finishing. This allows interior work to go forward quickly. This roof slab is exposed on top and insulated underneath by a suspended quilt and plasterboard ceiling. The cavity is ventilated against condensation. End walls of concrete and brick provide an adequate insulation value as do the timber cladding panels. These panels are ventilated internally.

The partition walls are faced with plasterboard and cut to a height slightly short of the ceiling. They are wedged into blocks on the ceiling and some space is left between wall and block for electric wiring. Demounting of walls is possible, but very difficult.

Typical heating ducts feed through the ceiling space of the ground floor. The system may support a variety of heating applications and provisions are made in the roof panels to allow for this flexibility.

Electrical installations may be placed on ceiling or wall as the chases are formed when the concrete is poured. Erection of the building is intended to be handled by a four ton crane for the structural elements, and a lighter crane for the partition walls and cladding panels.

Site layouts for this system will be restricted by the abilities of a crane, but the rate of construction can be as high as one unit per day for large multiple residence dwellings.

THE SYSTEM

The general aim of this project is to design an economically efficient prefabricated building system that is not dependant on highly repetitious spaces or forms, and therefore provides a viable alternative to conventional construction. Current prefabricated systems utilize a fair amount of repetition in order to economically compete with conventional methods of construction. This enforced repetition tends to create relentlessly uniform designs without any room for variation or a spatial organization in response to site and programmatic issues. I have developed a prefabricated building system that provides some of the design flexibility of platform framing but lacks the heavily layered development that accompanies this technique of construction. The proposed building system uses a stick frame structure that provides support for an interior, insulated enclosure, and an exterior, ventilated shell. The shell takes the form of a rain screen. The volume of the enclosure is lifted a few feet from the ground, creating minimal site impact and building/ground interaction. Mechanical systems may reside in zones created by the standardized structural frame and run through the space between shell and enclosure. Due to an arrangement of individual panels, the cavity that exists between the rain screen and enclosure is easily accessible, without any damage to the building, from the interior or exterior. The main advantages of the proposed system over conventional 2x4 constructions are that it is cheaper to build, has easier maintenance, and greater long term performance. This performance can be measured in energy efficiency, moisture resistance, and ecological impact. The main advantage the system has over typical prefabricated systems is its ability to conform to a variety of design demands, both functionally and spatially.

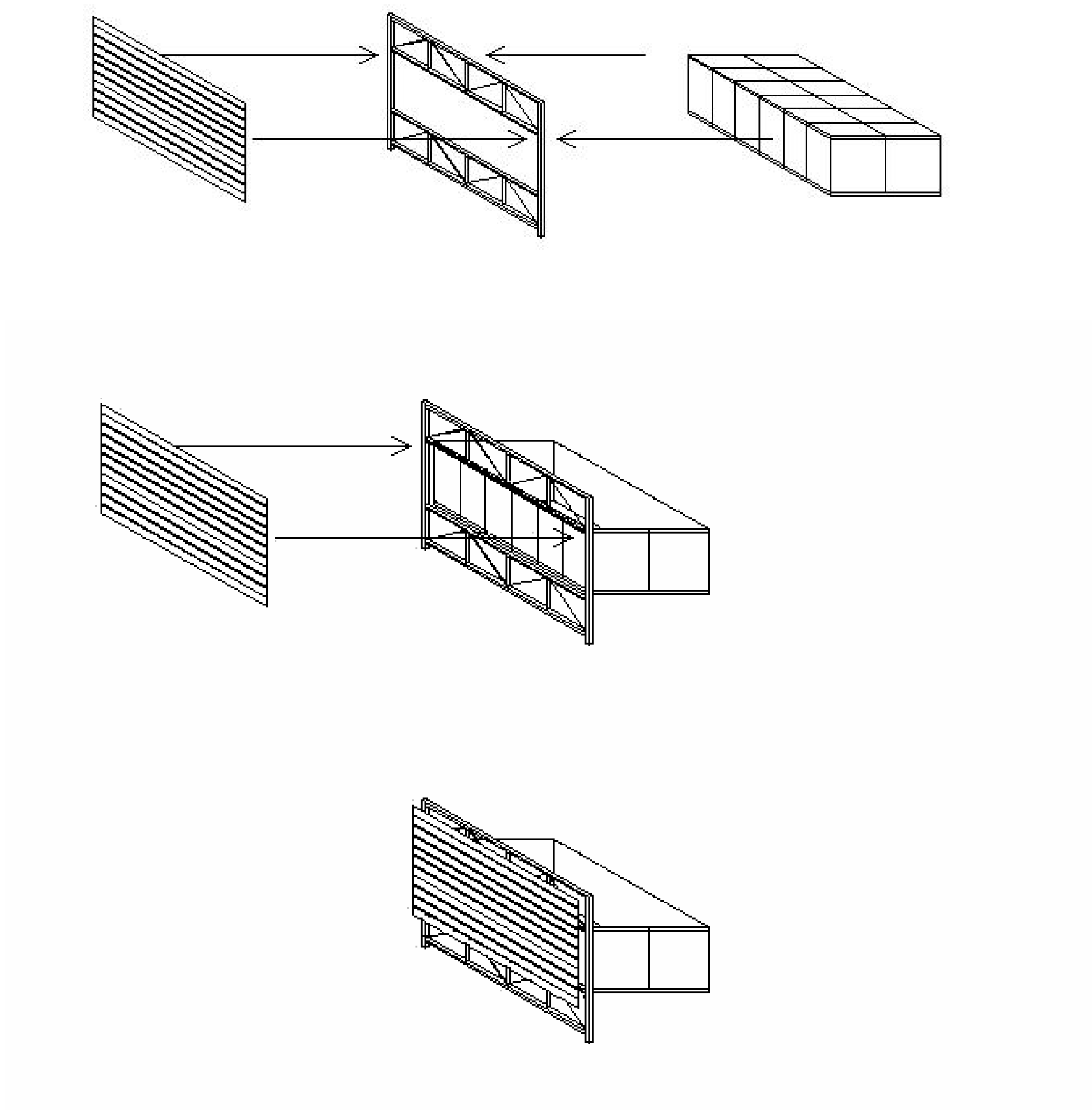


Figure 4 – System Concept

The system demonstrates a form of low cost, prefabricated construction that efficiently deals with vapor and thermal issues without using the typical layered systems. This is accomplished through the use of modular panels that will be built at low cost in a factory and used as infill/insulation. Doors and windows may be mounted into the infill panels. These modular pieces are interchangeable, allowing for easy, low cost maintenance.

The developed project includes a catalog of interchangeable parts which can be assembled by a client into a building (Appendix I). There are design choices for different arrangements within certain parameters set by the basic structural elements. The structural system is able to stand alone without any material or component imports. However, most of the catalog components and materials are interchangeable with custom parts. The system may be used to create its own building or additions that may interface with other forms of construction.

The two systems from which this system is derived are also its greatest competitors. My proposed system must show some advantages over traditional 2x (stick built) construction and standard Structural Insulated Panel (SIP) construction in order to be viable.

The panels that make up the enclosure walls are derived from the SIP concept. However there are two major differences between standard SIPs and the panels I have designed. First, all major panels in my system are sized at 4'x 8', which minimizes labor in the prefabrication process as plywood and polystyrene is distributed in this size initially. Any off-size panels are simply cut in the factory and belong to a limited set of standard sizes. On-site cutting is unnecessary and waste should be almost non-existent. The second difference is that wall panels are constructed of typical polystyrene boards and plaster board – window or door mountable wall panels have an exterior face of ¼" plywood providing stability. The simple enclosure wall panels possess insulation that is exposed in the ventilated cavity, allowing evaporation of any condensed water that may form at the dew point in the wall. The plaster may serve as interior finish, thereby eliminating further material and labor consumption.

The structure of my system is derived from a stick frame platform framing system. Essentially, beams have been replaced with trusses and floor joists have been replaced with the SIP floor panel. The greatest difference is that the structure is mostly separate from the enclosure wall and exists in its own ventilated cavity. This would increase the lifetime of the structure by protecting it from mold and rot. Advantages are summarized in Table 1.

Table 1. Advantages Over Derivative Systems

Advantages over 2x construction	Advantages over full SIP structure
- deals with moisture issues through use of ventilated cavity	- rainscreen cavity prevents moisture sink behind cladding
- all components are easily removable and replaceable, making maintenance easy	- removable components, easy maintenance
- mech/elec spaces are easily accessible	- easily accessible mech/elec
- better insulation	- cheaper construction
- cheaper construction	- less site impact than most SIP designs
- less site impact than most 2x designs	- no drilling mech/elec chases

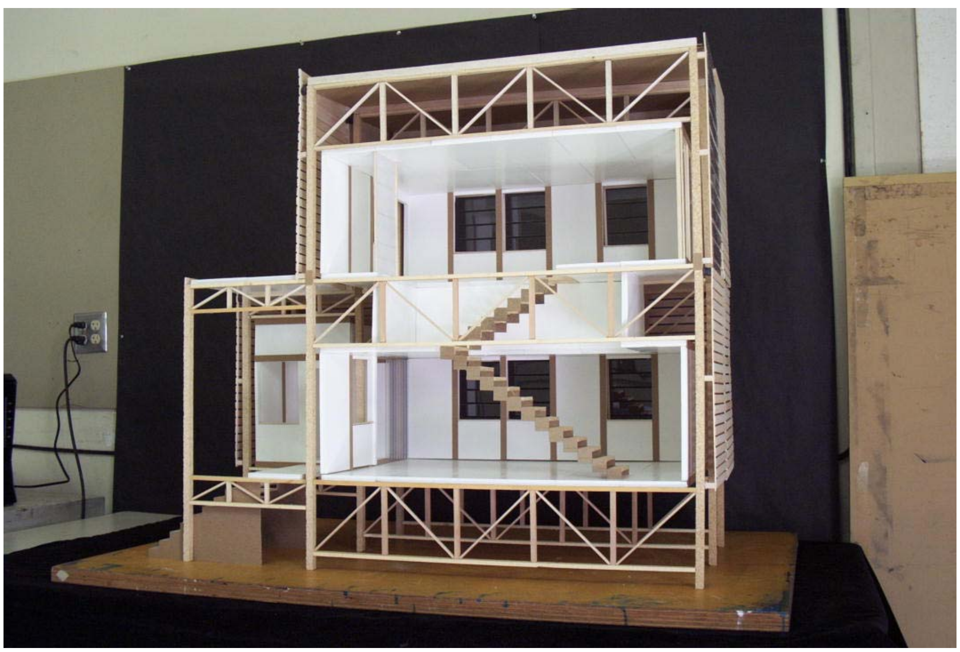


Figure 5 – System model using 25' truss and 9'truss

ECONOMY

One intention of this research is to determine a low cost, low maintenance, energy efficient, building strategy for a variety of program types. Regarding low construction cost, I intend to confront issues such as material expense, labor costs, and material and design integrity. Regarding low maintenance, I will explore issues such as material resistance to decay, design solutions for controlling moisture and dampness, and ease of replacement of failed components. Regarding energy efficiency, I intend to provide a design that meets or exceeds all current energy codes for homes, regardless of region.

The specific design of my building system is in response to the “layered” approach of construction where each new stage permanently buries the previous. This layered, or “on site”, construction creates a high labor cost and dependence on the expertise of the craftsmen. Also, any alterations or maintenance to the building often require costly and laborious efforts. The failure of vapor control systems on the inside of these layered structures has been a perennial issue.

The system that I have developed is based on the principle of using only manpower for construction. All the parts are based on a two to four person load and placement of the parts does not require any large construction equipment. In addition, economic value of the system is increased because all parts are prefabricated to match each other and experienced personnel are not needed for much of the construction. The logic of the system allows for cheaper labor without a loss in quality of construction. This attribute comes into play in low cost or charitable applications, such as a homeless settlement or Habitat for Humanity project, where many of the workers may be volunteers and of limited construction experience.

Regarding materials, in the United States, wood is by far the cheapest building material, and is thus the best choice for low cost construction. This automatically restricts the viability of the design to regions where wood is easy to acquire. Some regions of the world, such as Korea and Japan, have a small supply of timber and must often import wood for construction.

With the use of wood, one must take the responsibility to design carefully in order to protect the wood from decay, dampness, and insects. The first important decision is the type of wood to choose. Different species of trees have different qualities regarding strength, movement from moisture changes, resistance to decay and insects, and cost. The choice must be based on which wood provides the most benefits for the least cost.

Researching the nature of wood as a material is an important step in choosing a type to use. Wood is the only structural building material that was at one time an organism. The actual process of growth and survival of a tree creates the properties of wood as a construction material. Many of these properties are also related to water. In life, water sustains trees and the very cellular design of wood is based on the use of water. In order to be used for construction, the wood must be dried out, during which many physical changes occur. These changes are most extreme once all the free water has evaporated and the water that is bound to the cellulose in the cell walls begins to dissociate. Once this stage is reached, the wood has greater strength and decay resistance, and its dimensions change relative to the actual moisture content left in the cells. This dimensional change is known as movement and different woods have different movement properties (Table 2). Due to the hydrophilic nature of cellulose, all of these changes are reversible.

Table 2. Moisture Related Movement of Different Wood Types (Oliver, 1997).

Small movement (less than 3%)	Medium movement (3 – 4.5%)	Large movement (greater than 4.5%)
Afrormosia	Keruing	Beech
Douglas Fir	Oak	Birch
Western Hemlock	Scots Pine	Ramin
Iroko	Sapele	
Larch	Walnut	
Mahogany		
Seraya		
Teak		
Western Red Cedar		
Whitewood		

Different woods have different decay and insect resistance, as well as structural differences (Table 3). Different tree species have different environments with which to cope, and decay resistance and insect repellence often happen naturally. This resistance is a result of chemical deposits that the tree makes on its own tissue as it grows. This activity is an evolutionary response to environmental conditions and is most apparent in cedars and hardwoods. These types of trees have adopted biological strategies that allow them to survive in extreme environments. For example, cedars posses certain chemicals that act as insect repellants and are relatively resistant to molds. Recent research (Li & Cheng, 2003) has shown that many of the slow growing hardwoods have high decay resistance due to the presence of two types of lignins, or structural proteins, allowing them to survive in climates with high winds and moisture levels. The most resistant and structurally stable wood is also the most expensive, such as Oak or Teak. However, one type of wood that has good strength and relatively strong resistance is Douglas Fir. It is a common wood in the United States and its low cost makes it a good choice for construction.

Table 3. Durability of Different Woods – results are dependant on strength, insect resistance, and decay resistance (Oliver, 1997).

Life expectancy of 50 x 50mm stake in ground contact (years).

0-5	**5-10**	**10-15**	**15-25**	**25+**
All sapwood	Firs	**Douglas Fir**	Western Red	Afrormosia
Abura	Western	Larch	Cedar	Afzelia
Alder	Hemlock	Maritime Pine	Agha	Ekki
Ash	Baltic	African	Sweet	Greenheart
Balsa	Redwood	Walnut	Chestnut	Iroko
Beech	Whitewood	Keruing	American	Jarrah
Birch	Spruce	African	Mahogany	Kapur
Polar	Parana Pine	Mahogany	Meranti	Lignum Vitae
Willow	Elm	Sapele	Oak	Makore
	Obece	Seraya	Utile	Opepe
	Podo		Idigho	Teak
			Karri	Guarea
			Pitch Pine	Mansonia

If wood is kept at a sufficient moisture level, it will inevitably develop some kind of rot or decay. In construction, the most common type of rot is called Dry Rot and it occurs at or above 90% relative humidity. This most commonly occurs near places that would be considered moisture "reservoirs" (Fig. 3). These reservoirs may take the form of undrained ground, undrained wall cavities, damp masonry or timber masses, or improperly dried construction materials. In contrast to reservoirs, moisture "sinks" provide a large dry air mass to which the moisture can evaporate (Fig. 4). This is often achieved through different strategies of ventilation and drainage.

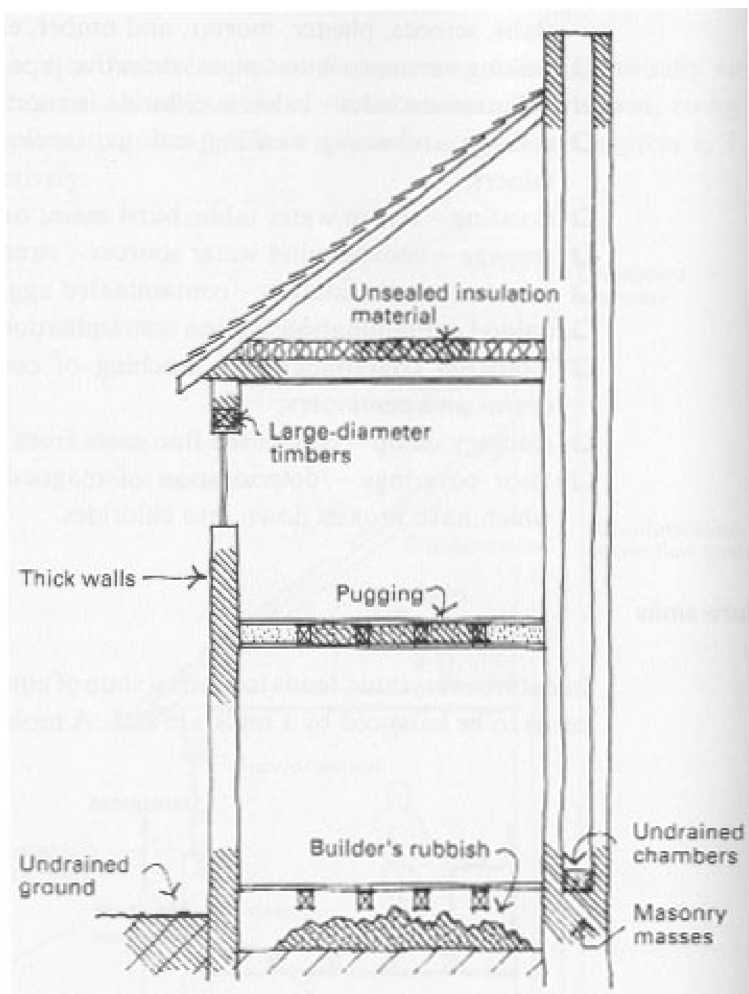


Figure 6 - Examples of Moisture Reservoirs (Singh, 1994).

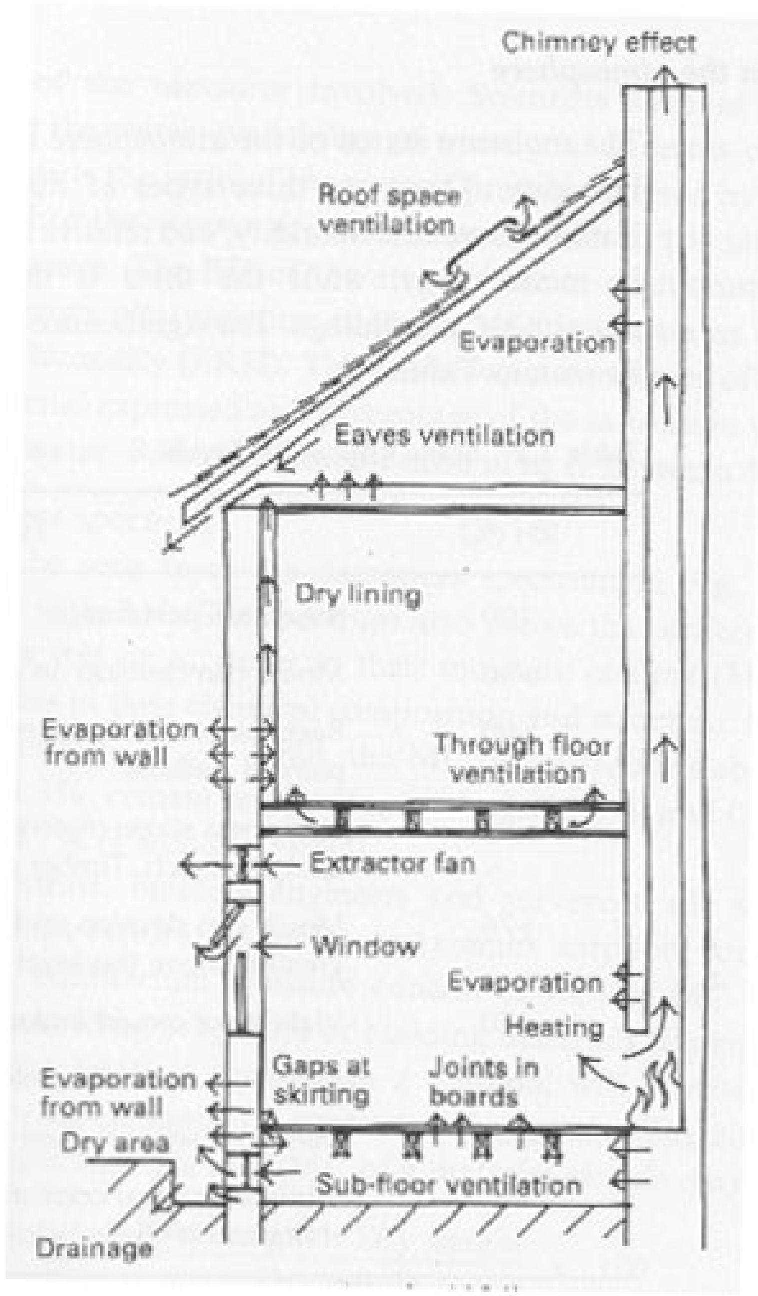


Figure 7 - Typical Moisture Sinks (Singh, 1994).

There are many design strategies that provide passive ventilation and drainage. In recent years, the rain screen principle has grown in popularity. This strategy provides a ventilated space between the insulation and the outermost layer.

The outermost layer prevents most water from reaching the insulation, and that which does is sent to a moisture sink via the ventilated cavity.

Another strategy for protecting structural elements from moisture is the curtain wall system. This system has been largely used with steel but there are indications that it would work well with a wood frame. A typical wood frame is susceptible to all of the moisture conditions that occur inside the wall. Bringing this frame out of the wall and into the house, or the cavity made by the rain screen, actually protects the wood from these conditions and provides a clear expression of the construction of the building.

Removing the structural frame from the enclosure wall will place new requirements on the enclosure skin. The skin will no longer have the main structure to use for stability. In addition, the cavities that are formed from traditional wood frame construction will no longer exist. These cavities are used to accommodate insulation. The challenge is to develop a design which allows the enclosure skin to have stability and be insulated without the use of wood frame elements. One approach is to use Structural Insulated Panels (SIPs) as the enclosure skin. These panels can provide the structural stability needed for wind loads and shear while also providing insulation and enclosure. Also, the panel design makes for easy replacement in the case of failure. This approach is radically different from the layered approach of traditional construction and could allow for easy access to mechanical and electrical systems.

The system I have developed is based on a 4’x 8’ module that can be expanded to enclose spaces with a maximum span of 24’ or longer if intermediate columns are included. There are three separate subsystems that work together to create the building – the shell, the structure, and the enclosure. The shell is a lightweight rain screen that protects the second system, the structure, from moisture and other harsh elements. The primary structure exists in a cavity between the rain screen and the enclosure and is both sheltered and ventilated, allowing the wood members to perform their tasks without the added stress of rot and mildew. The enclosure is the innermost layer and also acts as insulation. This is accomplished with the use of IPs (insulated panels). The enclosure walls are also based on a 4’x 8’ panel module and are interchangeable. Any 4’x 8’ panel, window, or door, will fit into this system, and doors or windows may be mounted into an IP before installation. Partition walls are, again, based on a 4’x 8’ module and can take the form of any 2” - 8” thick panel. They may follow a similar design to the 5M walls where gypsum board sandwiches a simple thermal and sound insulation. The partition panel is mounted into brackets that are attached to the floor and ceiling. The partitions are demountable for rearranging interior spaces and doors may be mounted into the panels. Space for mechanical and electrical systems is provided on the underbelly of the structure which is raised off the ground on concrete piers. These systems may also reside in the space between floors. Here, the mechanical systems are easily accessible and protected from the weather. My intention for incorporating mechanical systems into the building is to minimize custom work by providing visible and accessible conduits that run through the wall cavity and from which all networks originate or an insulated plenum made from wall panels (for colder climates). This last part is the least designable for a "catalog of parts" and will depend largely on the execution of a particular design with the system.

Labor costs are saved in wood construction by minimizing the number of cuts and custom work on site that needs to be done. There are three ways to do this. The first is to produce all custom work ahead of time in a factory setting, where machines and space are already prepared for the work. The second is to incorporate "lumber yard dimensions" into the design. Lumber yard dimensions are those dimensions at which we find lumber pre-cut at the lumber yard. In using these dimensions, we are letting the lumber producers do much of the labor for free. Finally, the design itself may be conducive to ease of construction through simple relationships and allow for timely generation by inexperienced personnel (cheap labor).

It is important to note also that a low cost building does not only include the initial construction costs. The cost of use and maintenance over time is also an important factor. For example, a poorly insulated house in a cool climate will generate tremendous energy bills. A building that requires custom construction as part of its maintenance will also require large funds. Good insulation strategies are critical in a design that intends to produce a house that is low maintenance and has long term efficiency.

Finally, I performed a brief cost comparison summary between my system and competing systems. I used the data from a NAHB (National Association of Home Builders) study – Comparative Costs of Alternative Building Systems in New Residential Construction – and compared it to the same data from my own system. In summary, the study provided an estimated list of costs for different framing components of a conventional two-story house with attached garage. The living space is approximately 2000sf and the total costs do not include windows, doors, finishes, or utilities. This study really investigated the simple costs of conventional framing material and labor costs, making it a great study with which to compare my system.

In summary of this cost comparison sheet (Appendix II), the cheapest method for constructing a two-story house was using dimensional lumber for the floors, exterior/interior walls, and using wood roof trusses. The total for materials and labor for framing was only $17,607! The basic framing of my system works out to be $10,212 – 33% cheaper.

In order to clarify this claim, I paid a professional cost estimator to analyze the system. His initial opinion was that my system would be 25% cheaper than conventional construction. I ran numbers that compared a 2000sf dimensional lumber enclosure to the same size enclosure with my system (Appendix II). For material costs alone, a dimensional lumber system costs $22,163, whereas my system costs $13,922 – about 37% cheaper. Labor costs are estimated to be 20% cheaper, long term maintenance costs 20% cheaper, and energy savings 10% cheaper. After all custom work is complete, 25% cheaper seems like good estimate (it better be… it cost me $100).

FLEXIBILITY

In designing a prefabricated building system, it is my preference to expose and express systems and components, visually defining the manner in which all parts work. This does not, by any means, negate the possibility of a beautiful building. In fact, it is an opportunity to celebrate the advantages given us by technology. Individualization of each design is key in creating a system for factory built housing that that does not stifle the user with relentless standard spaces and materials. This requires the system designer's attention to flexibility and interchangeable parts.

The system designed for this project is based on the concept of attaining spatial flexibility within an inflexible structure. This is accomplished by using enclosure panels that may create space in an almost limitless number of arrangements within the structural frame. Simply put, the frame is the constant while the enclosure is the variable. The rainscreen falls somewhere between the two as it may be left off of certain parts of the building that are not subjected to heavy elements. It also may exist as any horizontal arrangement of wood and glass slats.

As stated earlier, in order to find a balance between the opposing conditions of custom and prefabricated I had to make decisions regarding the nature of different building components and the groups to which they belong. Some parts could be completely standardized while others could be left custom in order to accommodate the tastes and preferences of different users.

In the system I have developed, the parts that are left completely custom are those that possess a tactile quality in the everyday experience of the inhabitants. Specifically, I have not standardized openings such as doors or windows, finishes, partition walls, and mechanical/electrical systems.

It is simple to explain the tactile qualities of doors, windows, and finishes, whereas mechanical/electrical systems tend to have a removed physical presence from the mainstream activity of daily life. However, these systems produce some of the most tactile and elemental features in the built environment - light, water, and heat. Due to the huge variety of systems for heating and distributing water and air, and the immense array of lighting and electrical possibilities, I have allowed these systems to remain custom. In essence, the most intimate features of the building may be personalized and given a character of their own.

Some parts of a construction system require a degree of flexibility but do not need to be completely customized. Specifically, these are enclosure walls and exterior cladding. Space defining enclosure walls need the flexibility to move around for different designs and programs. However, they do not need the same personalization as a window sill or door knob. Cladding needs very little personalization but must be able to respond in some way to existing context and the exterior aesthetic preference of the owner. The enclosure walls and cladding are standardized but interchangeable in a way that allows a fair amount of design flexibility.

I have produced a number of diagrams that will help to describe what types of planar and sectional arrangements are possible with the system.

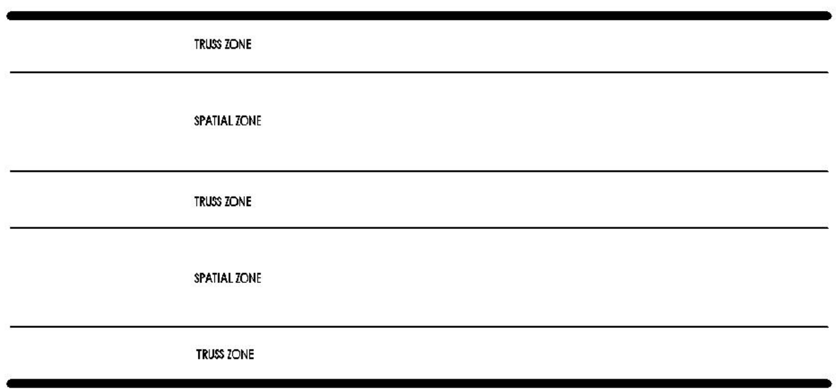


Figure 8 – System Zones; the frame produces a rigid horizontal arrangement of different zones created by structural elements and the spaces they create.

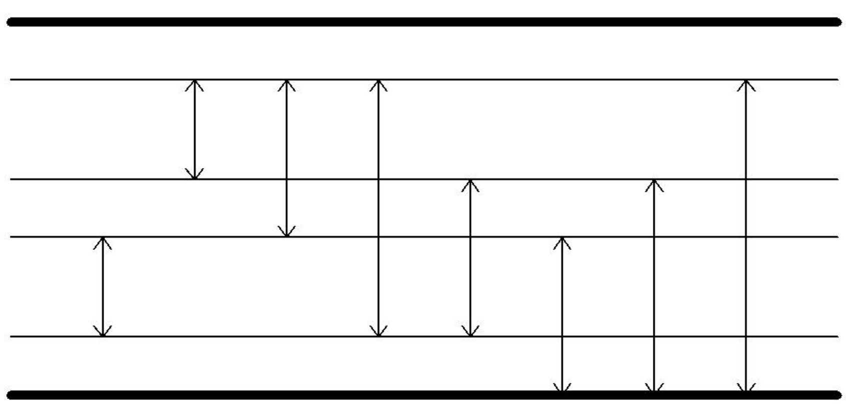


Figure 9 – Some Possible Wall Heights; walls may pass through the bottom two truss zones, allowing double height spaces.

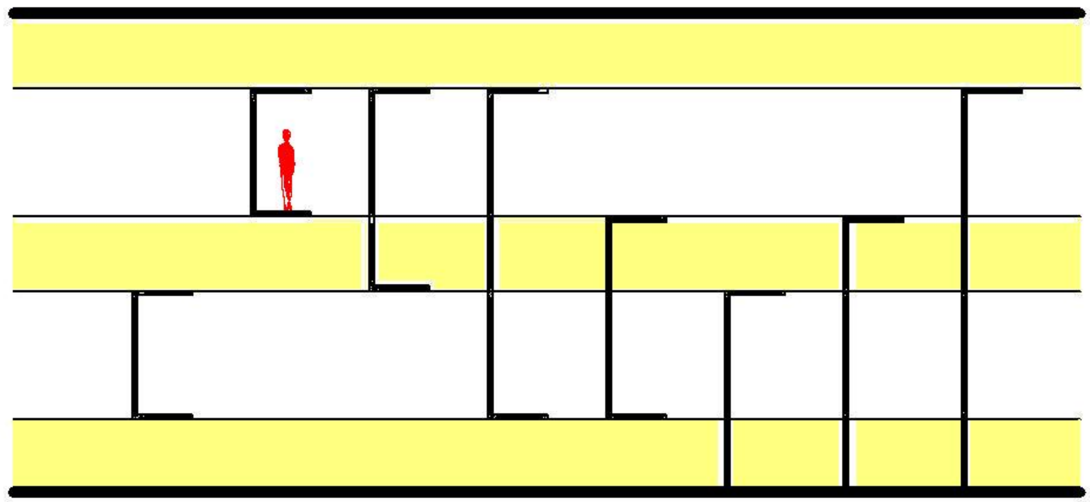


Figure 10 – Basic Wall Sections

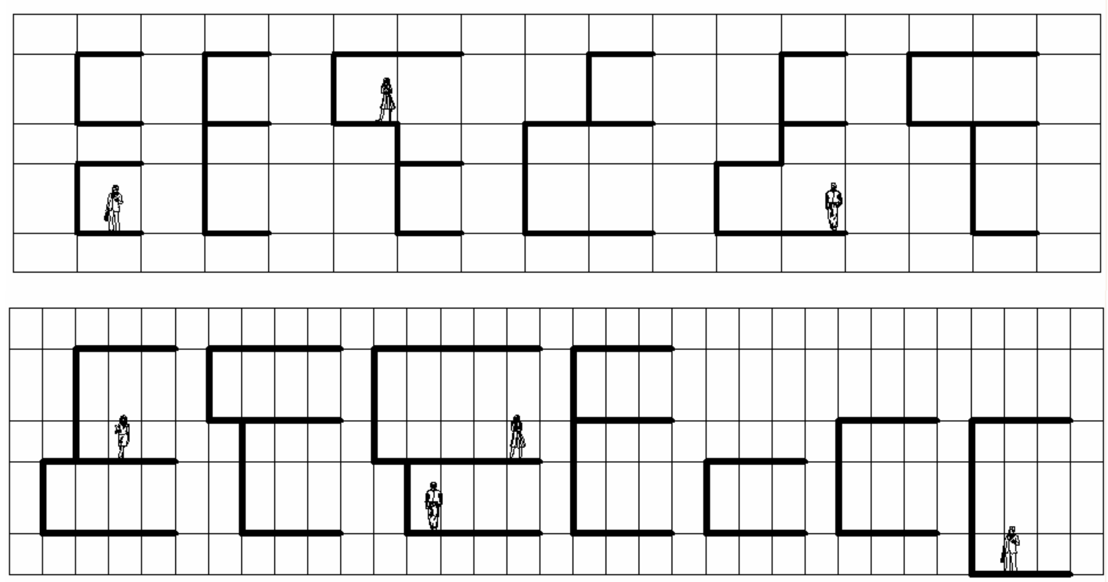


Figure 11 – Some Possible Sectional Arrangements (parallel and perpendicular to truss)

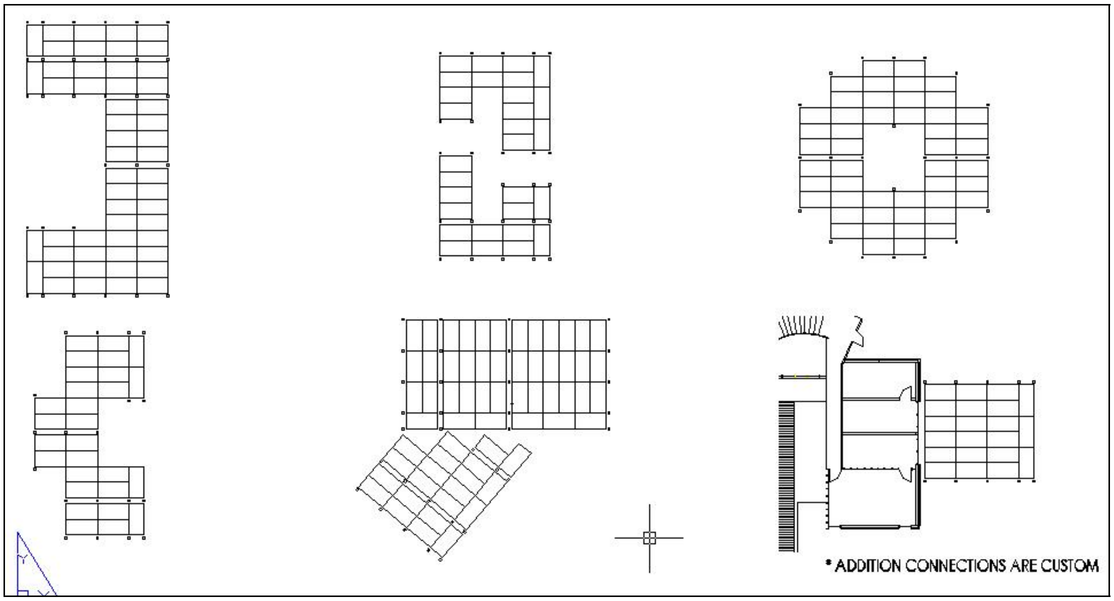


Figure 12 – Some Possible Plan Layouts; interface between system and existing structure in an addition would be custom.

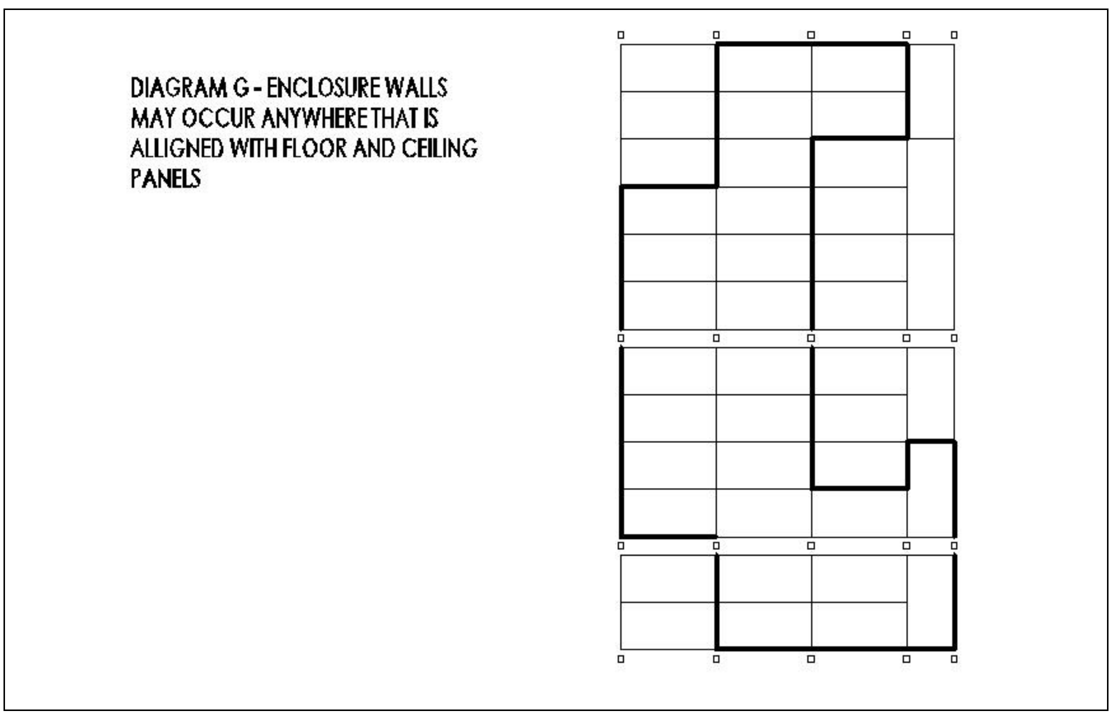


Figure 13 – Relationship of Enclosure Walls to Structural Frame

APPLICATIONS

I have chosen to investigate different possibilities for the system by establishing a few diagrammatic designs that test the system in different situations. The greenhouse was used to explore the potential of the enclosure walls to pull away from the boundaries set by the structure. Using a full glass rainscreen, I was able to enclose a large day-lit area with smaller areas of enclosure. This allowed for 2 levels of planting space, accompanied by fully enclosed and insulated spaces for more climate controlled plantings. The interior space may allow for a live-in botanist.

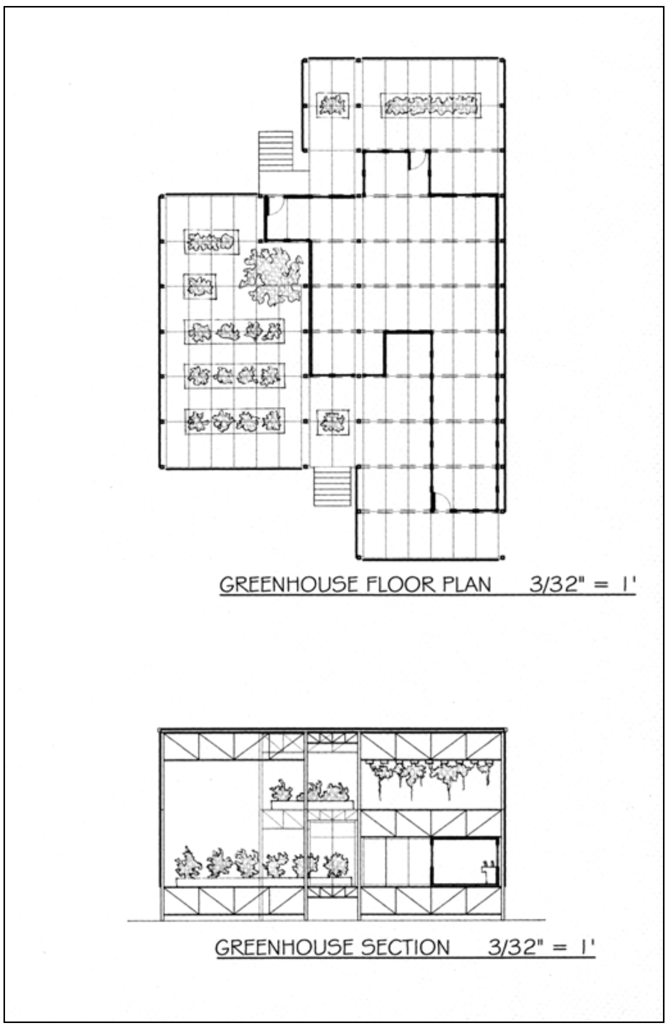


Figure 14 – Scan of greenhouse drawings; not to scale

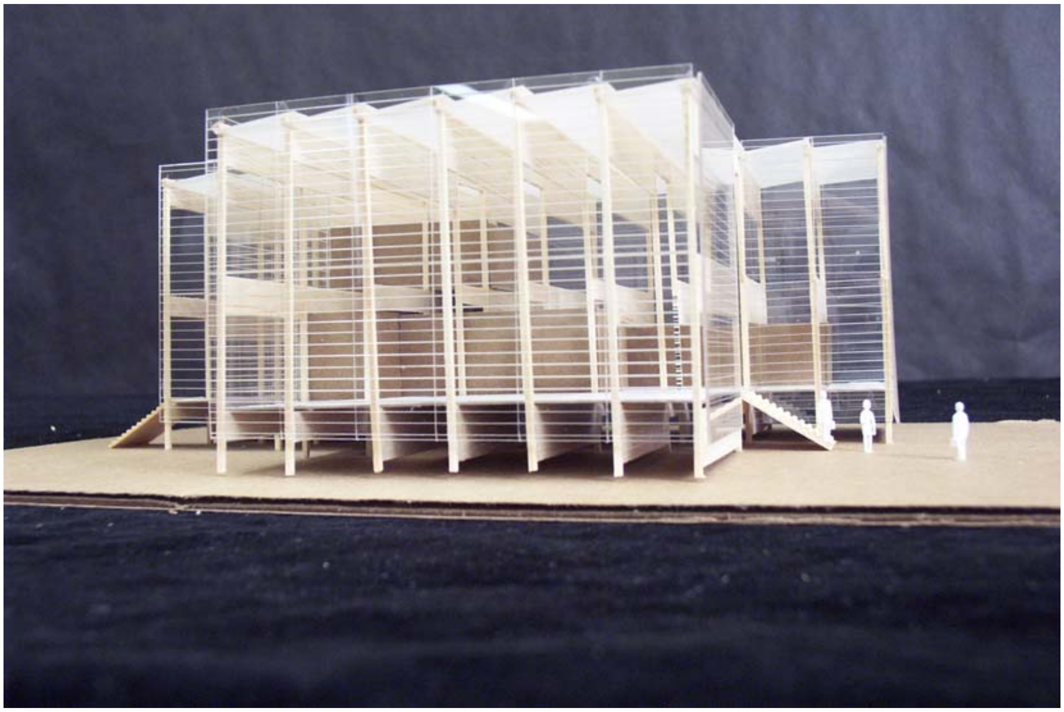


Figure 15 – Greenhouse model

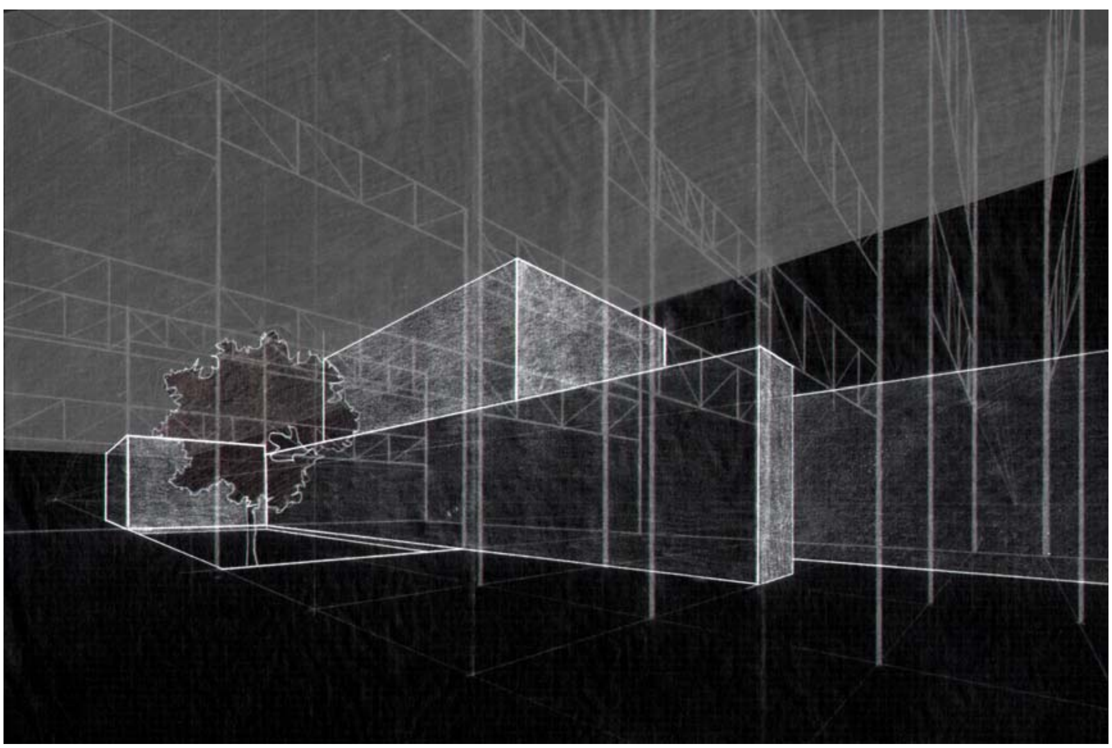


Figure 16 - Greenhouse interior perspective

The townhouse was chosen as a program in which façade manipulation becomes an important issue. Here, context and fabric impose some requirements on the design of the façade. The system responds to non-material features of the surrounding context. One drawback to the system in this application is that in order to match height with surrounding context, a concrete plinth and front wall must be used. In addition, my system provides two floors of program space to the surrounding building's three.

Figure 17 – Scan of townhouse drawings; not to scale

Figure 18 – Townhouse model

Figure 19 – Townhouse façade perspective

The church was used to explore the system's potential for assembly occupancy and double height spaces. This was one of the more complicated arrangements in regards to necessary spatial transitions. The system demonstrated a clear ability to form large double height spaces and work to rigid plan requirements.

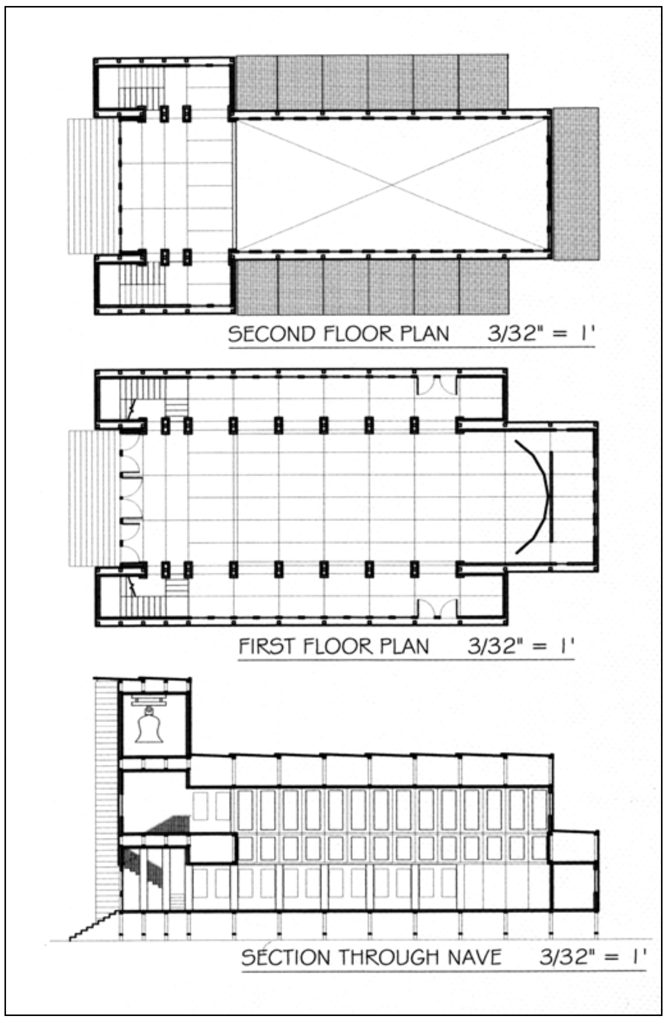


Figure 20 – Scan of church drawings; not to scale

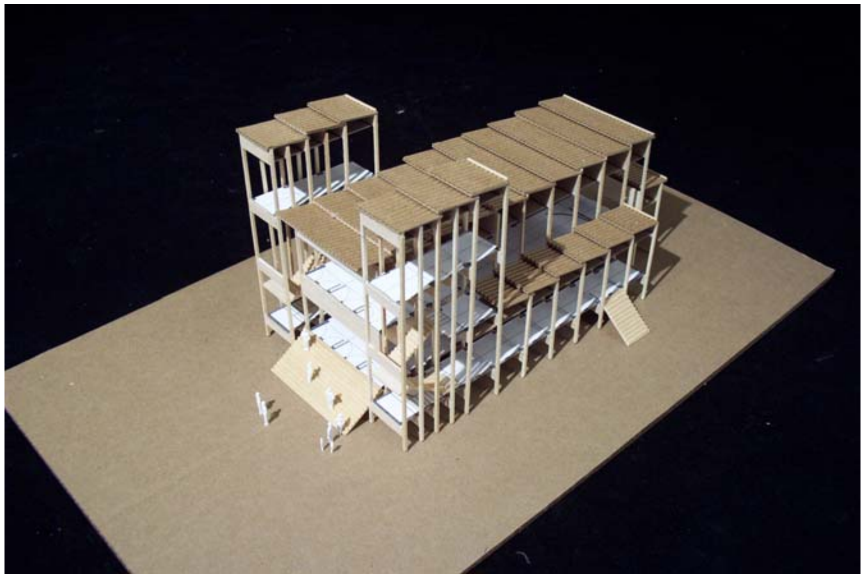


Figure 21 – Church model

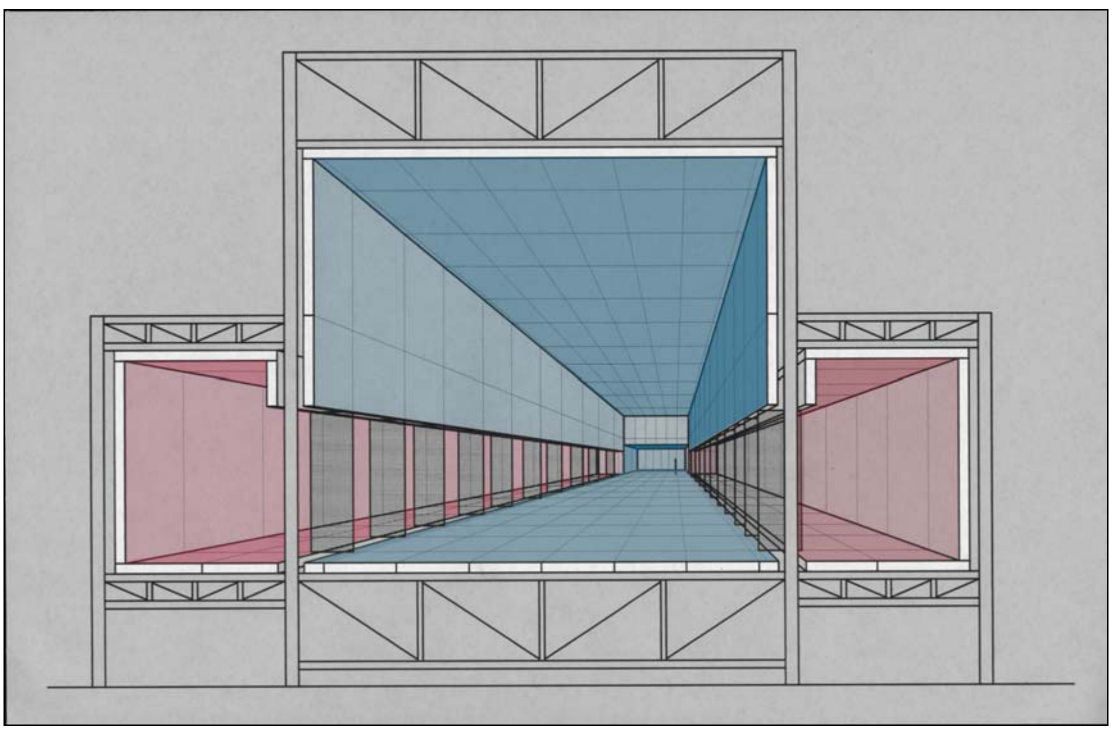


Figure 22 – Church section/perspective

The hillside home was used to explore the system's ability to adapt to variable topography. The variable levels of the system provided some answers to the problem but were unable to match the topography perfectly. In order to accommodate the variations, I determined that extended concrete piers and walls would need to be used. The amount of concrete used is minimized by the systems ability to change levels along with the topography.

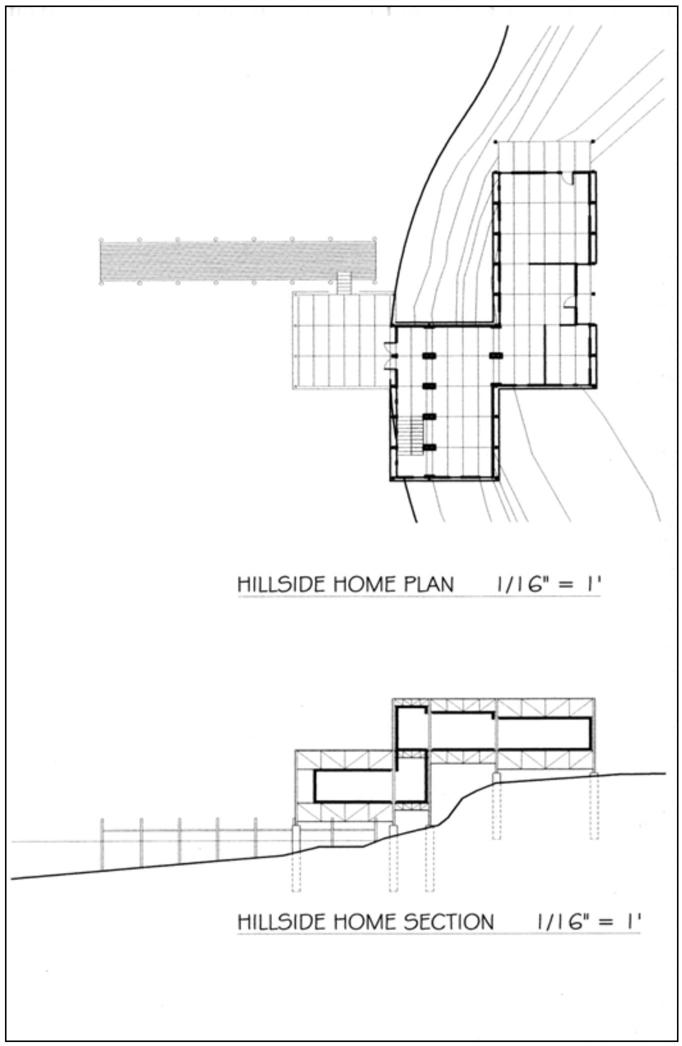


Figure 23 – Scan of hillside home drawings; not to scale

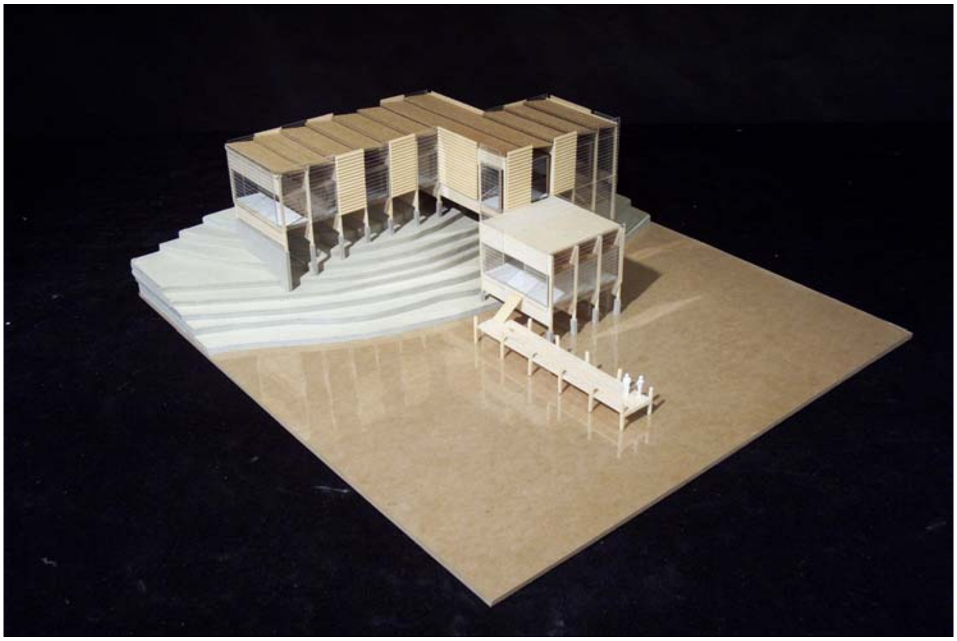


Figure 24 – Hillside Home model

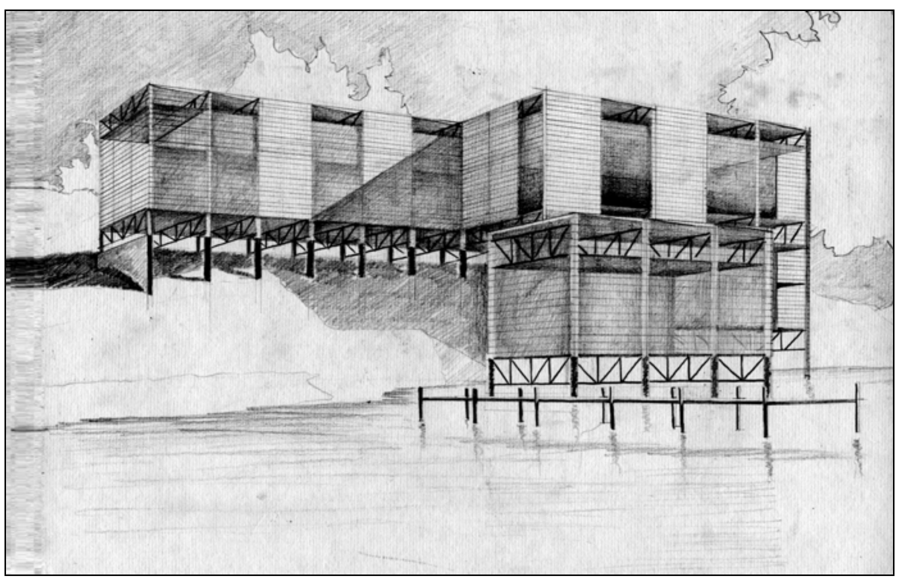


Figure 25 – Hillside home perspective

The economy shelters demonstrate three of the most minimalist structures that can be built from the system. They demonstrate the basic economic value of the system as well as the relationship between square footage and economic efficiency.

The smallest shelters have the highest ratio of enclosure wall to program area and hence, the economic efficiency is lowest of the three at $28.34 per square foot. The midsize shelter works out to be $16.23 per square foot, and the largest shelter is $12.39 per square foot.

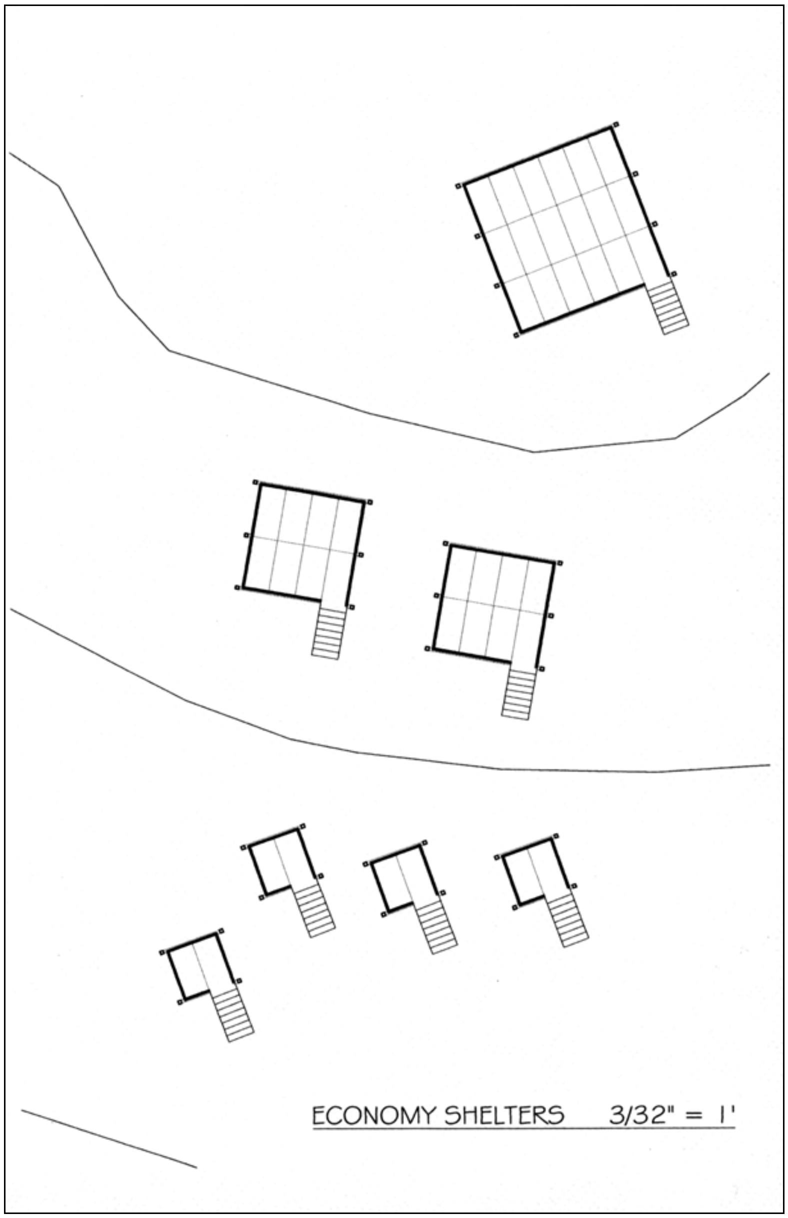


Figure 26 – Scan of shelter drawings; not to scale

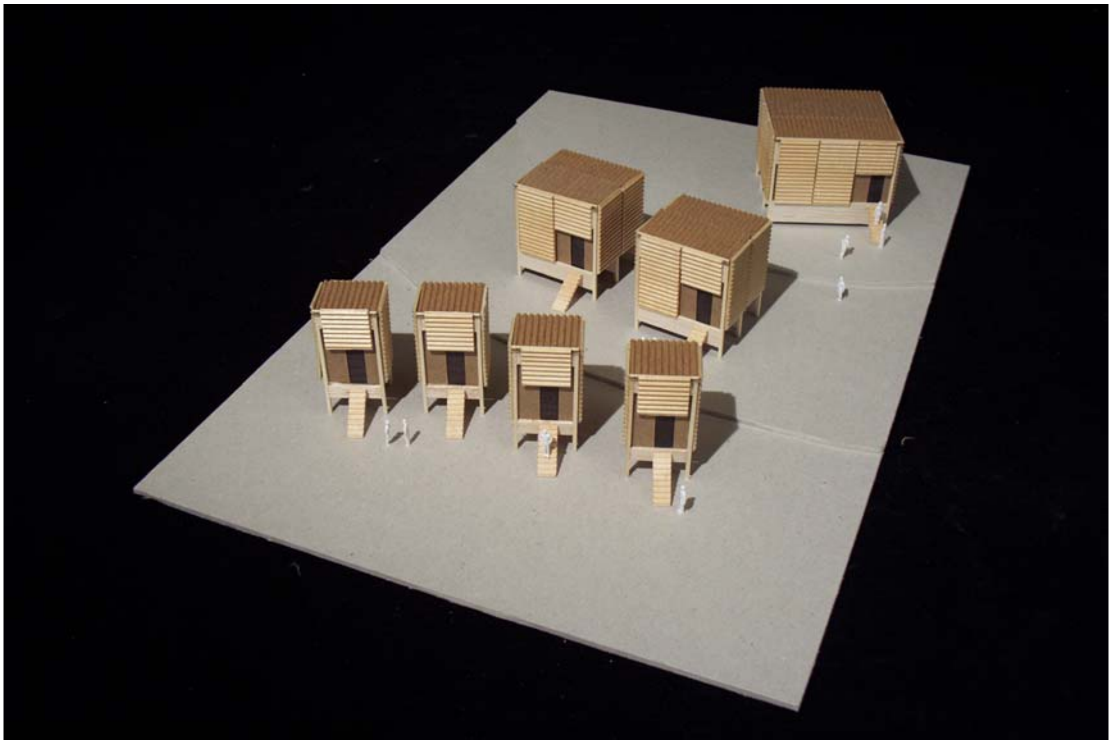


Figure 27 – Shelter models

REFERENCES

Arieff, Allison and Bryan Burkhart. PRE FAB. Utah: Gibbs Smith Publisher, 2002.
A brief history of prefabrication along with various contemporary examples.

Brown, G.Z., and Mark DeKay. Sun, Wind, and Light. New York, NY. John Wiley & Sons, Inc., 2001.

Brundrett, G. Criteria for Moisture Control. London, UK: Butterworths, 1990.
Lays out causes and solutions for moisture problems in buildings.

Cook, Peter. Archigram. New York, NY. Princeton Architectural Press, rev. 1999.

Croome, Derek, and A F. Sherratt. Condensation in Buildings. London, UK: Applied Science Ltd., 1972.
Lays out causes and solutions for condensation in buildings. Discusses rot resistance, etc.

Ching, Frank. Building Construction Illustrated. New York, NY. John Wiley & Sons, Inc., 2001.

Diamond, Jared. Guns, Germs, and Steel. New York, NY. W.W. Norton & Co., 1997.

Diprose, Alan. "The System Built Environment." The Architects' Journal May 1966: 1110-1165.
Discussion of prefabrication from the 1960's in Europe and provides a variety of examples.

Frampton, Kenneth. Modern Architecture: A Critical History. New York: Thames and Hudson, 1992.
Recent history of prefabrication and discussion of the architects that supported its use.

Hart, Sarah. "Prefabrication, the Speculative Builders Tool, Has Been Discovered by Modernist Designers." Architectural Record December 2003: 123-130.
Discussion of the very recent rediscovery of a prefabricated style.

Herbert, Gilbert. Pioneers of Prefabrication: The British Contribution in the Nineteenth Century. New York, NY. Princeton Architectural Press, 1978.

Kostoff, Spiro. A History of Architecture. New York: Oxford University Press, 1995.
History of prefabrication from early recorded history through to modern times.

Laigeng Li, Xiao Fei Cheng, Jacqueline Leshkevich, Toshiaki Umezawa, Scott A.Harding, and Vincent L. Chiang. The Last Step of Syringyl Monolignol Biosynthesis in

Angiosperms Is Regulated by a Novel Gene Encoding Sinapyl Alcohol Dehydrogenase. Plant Cell 13: 1567-1586, 2003.
Scientific study exploring the evolution of hardwoods – their rot and insect resistance.

Marsh, Paul. Air and Rain Penetration of Buildings. Lancaster, UK: The Construction P Ltd., 1991.
Techniques for ventilation and exterior moisture control.

Meurer, Bernd, Robert Ohl, and Gunter Schmitz. "Industrialized Building Studies at the HfG, Ulm." Architectural Design July 1965: 340-360.
Theoretical explorations of modules, repetitive forms, and industrial designs that could be conducive to building systems. Various closed systems for buildings and building components are proposed.

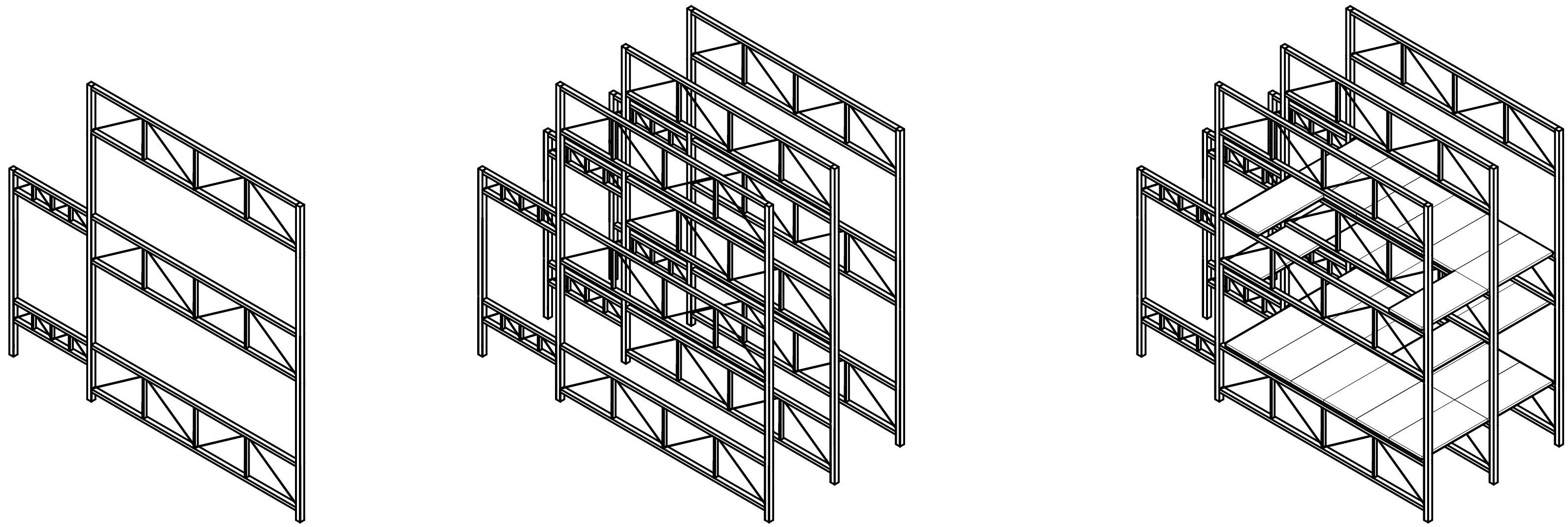
Morley, Michael. Building with Structural Insulated Panels. Newtown, CT. Taunton Press, 2000.

Oliver, Alan. Dampness in Buildings. 2nd ed. Oxford, UK: Blackwell Science, 1997.
Case studies, scientific principles, and control techniques of moisture in buildings.

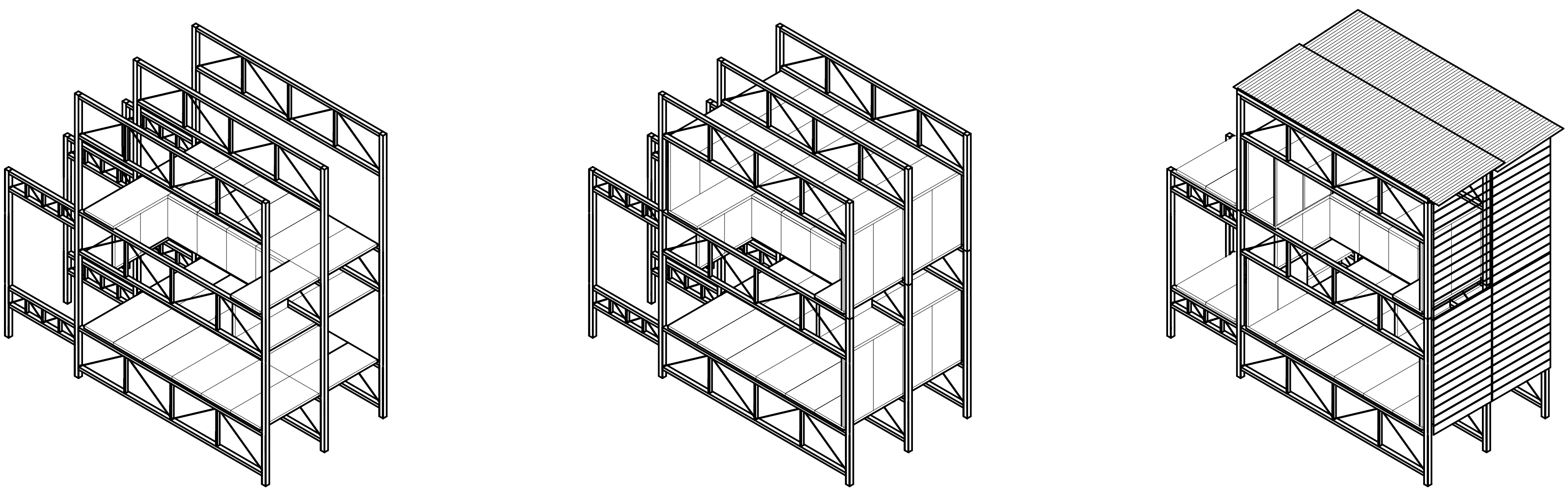
Pearson, Karl G. "Industrialized Housing." The Building Official and Code Administrator Nov. 1972: 19-24.
Code requirements for past prefabricated projects.

Researchers Discover Gene That Could Be Key in Hardwood Evolution. Vers. 1. July 2001. School of Forestry and Wood Products. 7 Nov. 2003 <http://www.admin.mtu.edu/urel/ttopics/textfiles/2001/-July-13-01.html#gen74>.

Schuyler, David. Apostle of Taste, Andrew Jackson Downing. London, UK. The Johns Hopkins University Press, 1996.



A PREFABRICATED STRUCTURAL FRAMING AND ENCLOSURE SYSTEM



GUIDING PRINCIPLES

In the realm of construction types there are two very polar conditions. One condition is that of complete customization, where every material, space, and connection are designed specifically for the structure at hand. The opposing condition is that of complete standardization where every material, space, and connection are literally or conceptually prefabricated and designed without regard to any particular project or site needs.

The system I have developed is intended to find a balance between these opposing conditions. In order to do this (allowing certain elements of the system to be custom, others to remain flexible, and others to be standardized) I had to make decisions regarding the nature of different building components and the groups to which they belong. Some parts could be completely standardized while others could be left custom in order to accommodate the tastes and preferences of different users.

In the system I have developed, the parts that are left completely custom are those that possess a tactile quality in the everyday experience of the inhabitants. Specifically, I have not standardized openings such as doors or windows, finishes, circulation(stairs), and mechanical/electical systems.

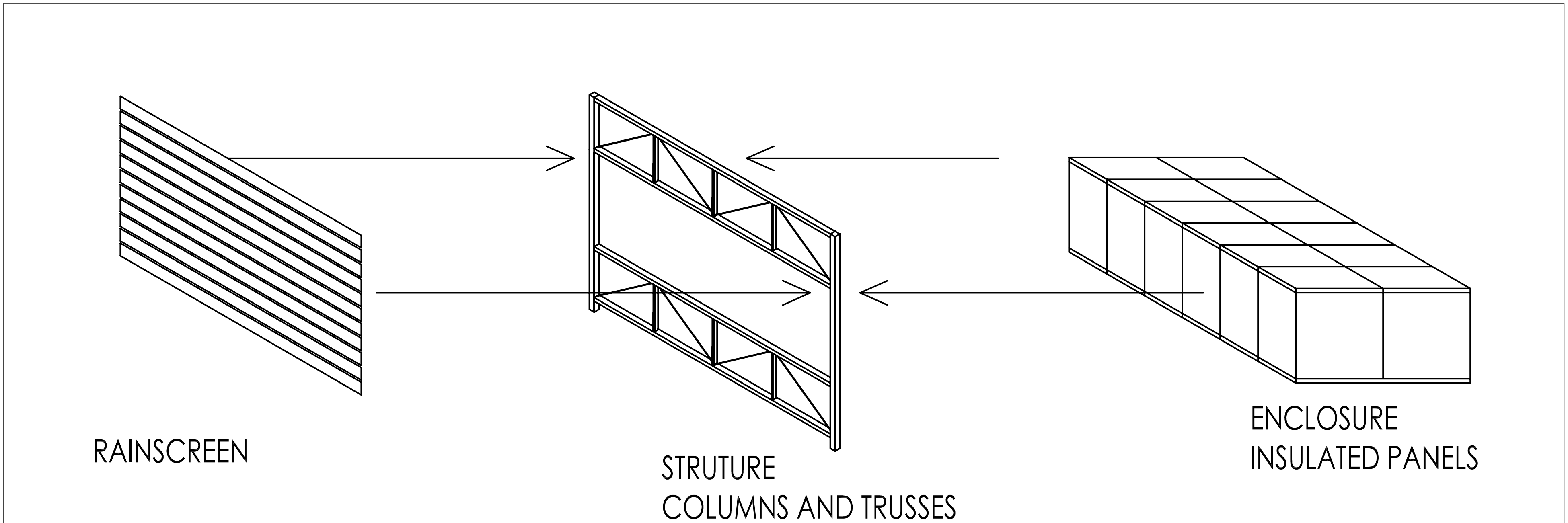
It is simple to explain the tactile qualities of doors, windows, and finishes, whereas mechanical/electrical systems tend to have a removed physical presence from the mainstream activity of daily life. However, these systems produce some of the most tactile and elemental features in the built environment - light, water, and heat. Due to the huge variety of systems for heating and distributing water and air, and the immense array of lighting and electrical possibilities, I have allowed these systems to remain custom. In essence, the most intimate features of the building may be personalized and given a character of their own.

Some parts of a construction system require a degree of flexibility but do not need to be completely customized. Specifically, these are enclosure walls and exterior cladding. Space defining enclosure walls need the flexibility to move around for different designs and programs. However, they do not need the same personalization as a window sill or door knob. Cladding needs very little personalization but must be able to respond in some way to existing context and the exterior aesthetic preference of the owner. The enclosure walls and cladding are standardized but interchangeable in a way that allows a fair amount of design flexibility.

Of all the building parts, the structure is the most removed from the intimate details of daily life. It is the quiet giant that supports the lives and settings we create within it. The structure in this system is completely standardized.

SYSTEM CONCEPT

3 DISTINCT LAYERS



- RAINSCREEN AND ENCLOSURE WALLS ARE DEMOUNTABLE

- ENCLOSURE WALLS MAY BE ARRANGED FREELY WITHIN THE STRUCTURAL FRAME

SECTION DIAGRAMS

Of particular importance is the relationship of enclosure to structure. These relationships are explored in the following diagrams.

Diagram A
The rigid organization of the structural system creates a number of zones. In section, the zones created by the trusses (also known as marginal truss zone) sandwich larger spatial zones.

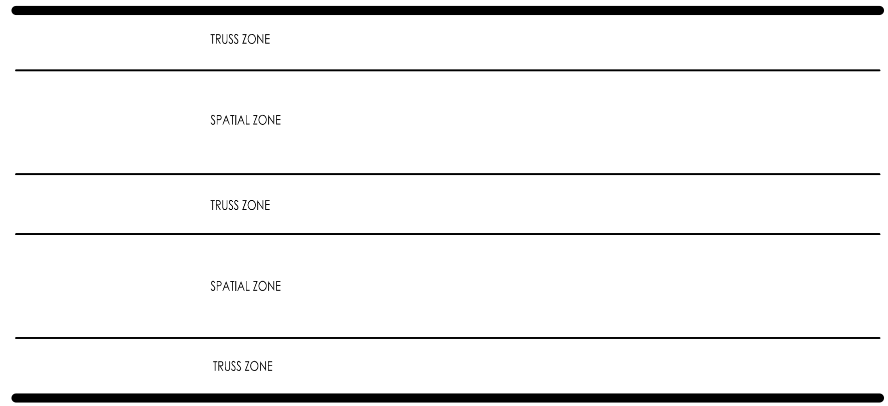


DIAGRAM A - ZONES

Diagram B
Within the different zones, there are a variety of different wall heights that are possible.

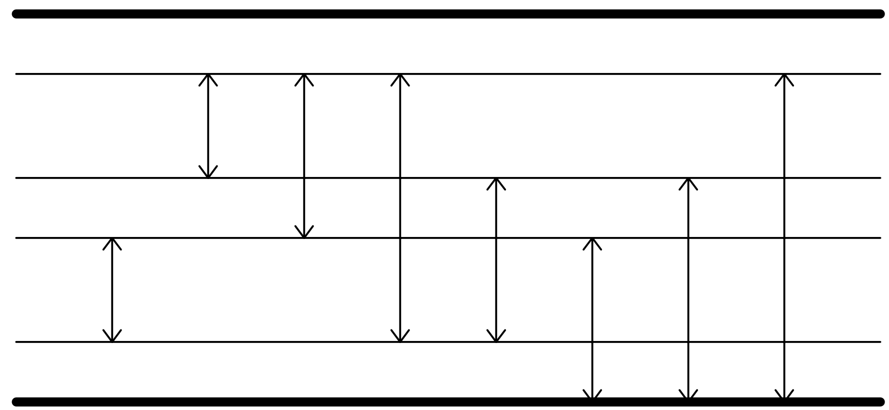


DIAGRAM B - WALL HEIGHTS

Diagram C
Each possible wall height provides a template for possible sections.

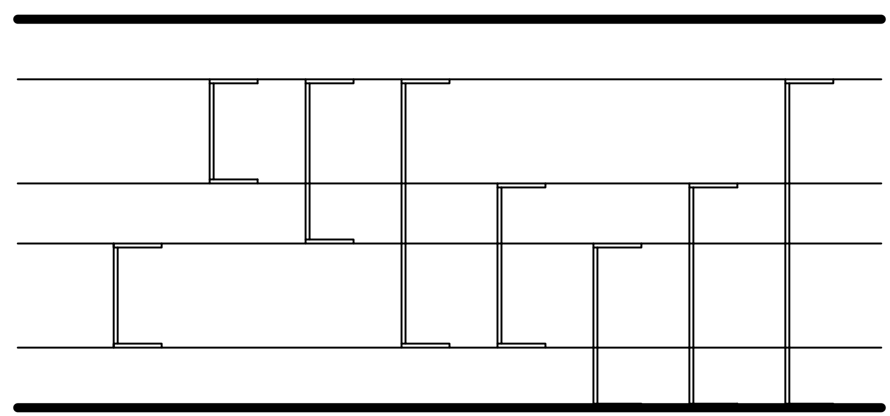


DIAGRAM C - WALL SECTIONS

SECTION DIAGRAMS

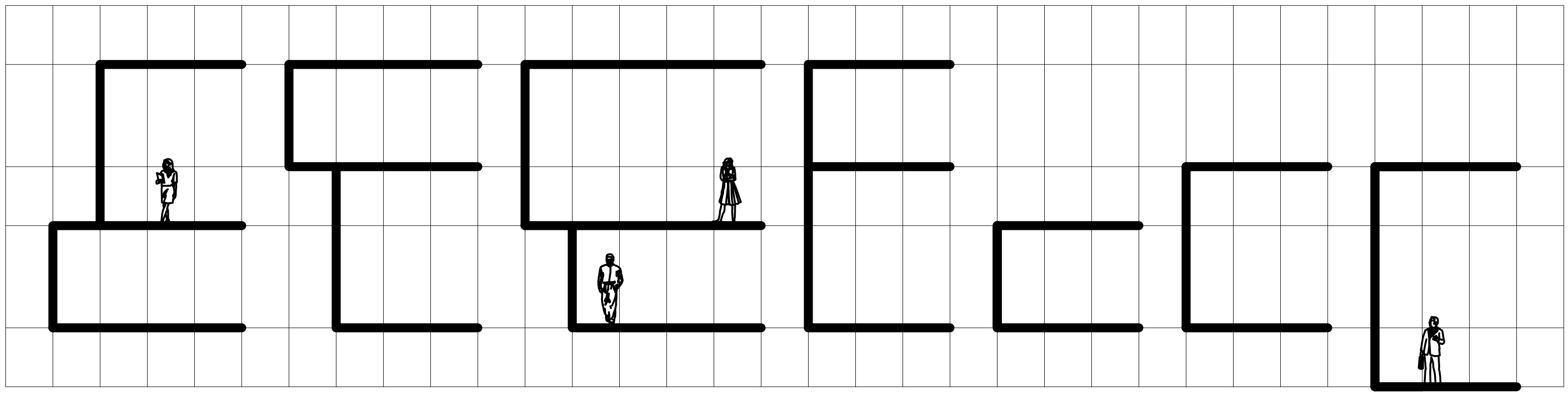


DIAGRAM D - SOME POSSIBLE SECTIONAL ARRANGEMENTS PARALLEL TO TRUSS

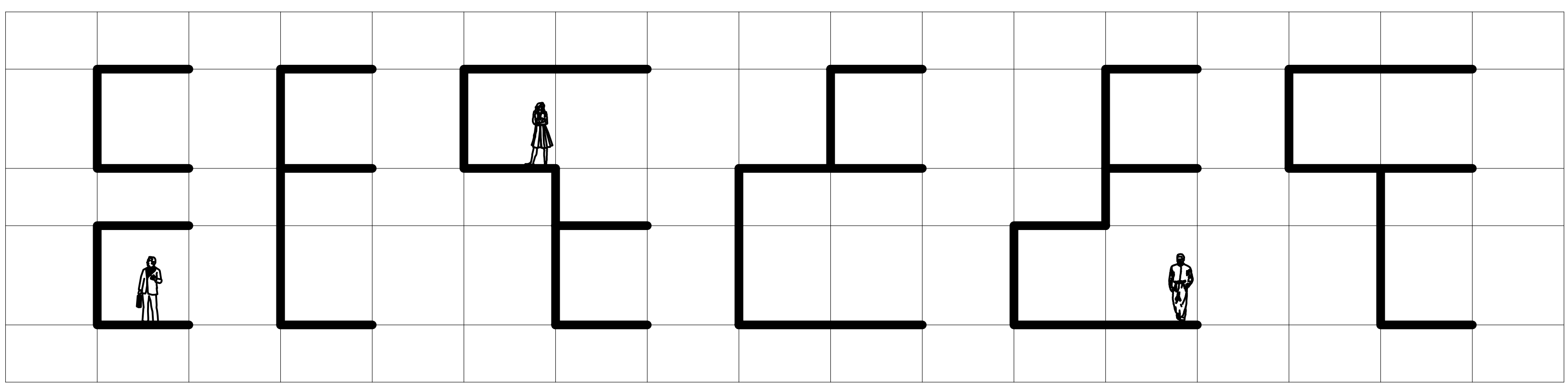
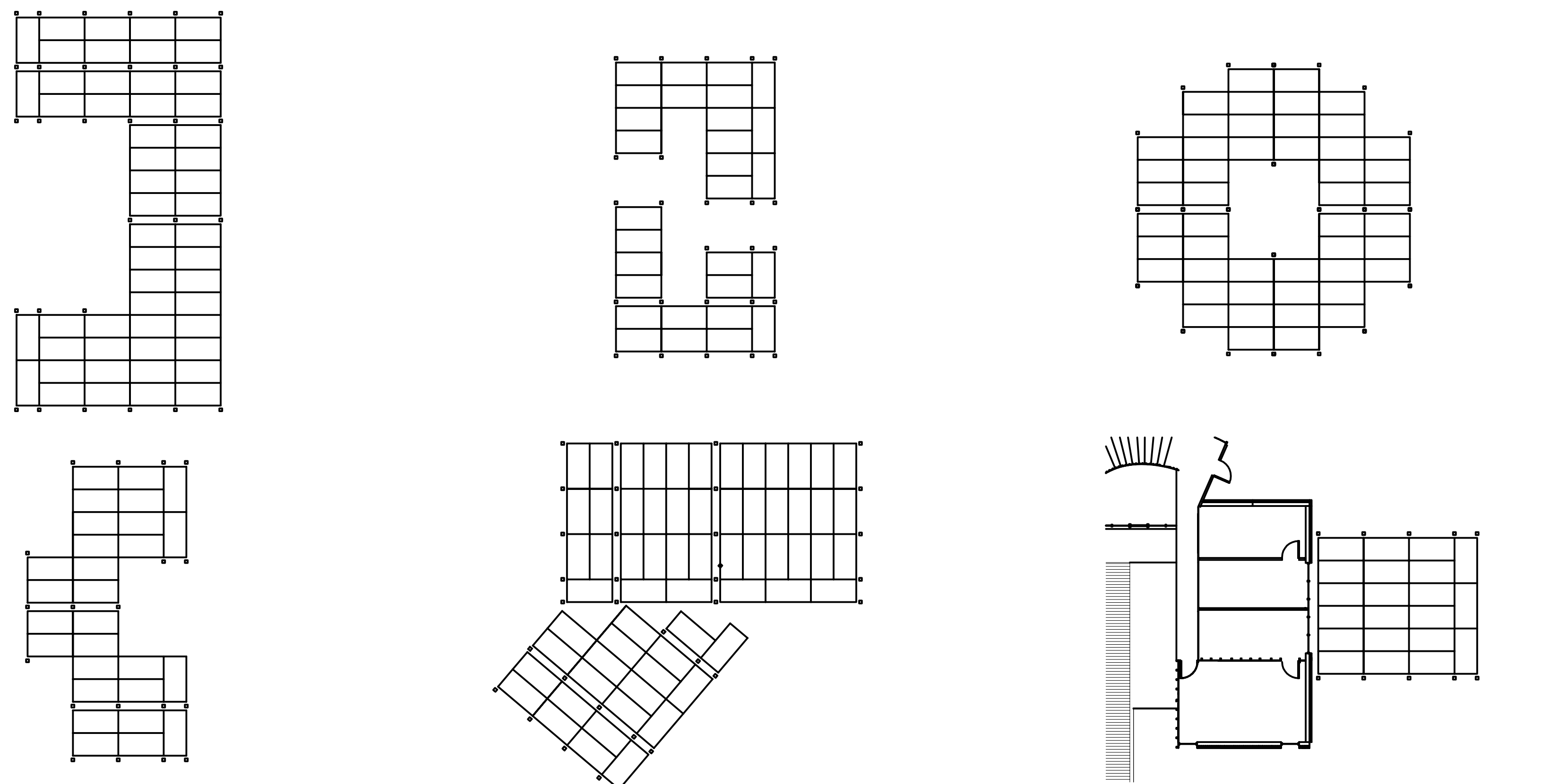


DIAGRAM E - SOME POSSIBLE SECTIONAL ARRANGEMENTS PERPENDICULAR TO TRUSS

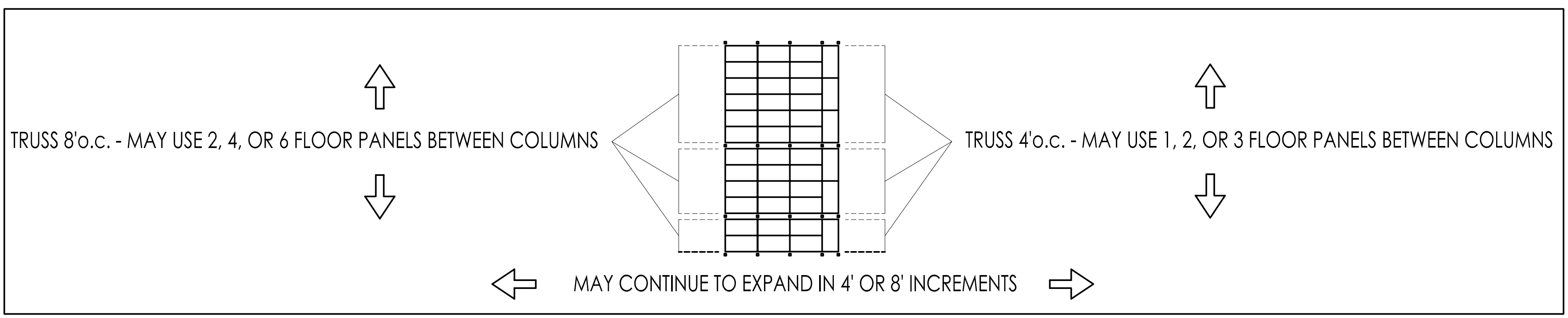
PLAN DIAGRAMS

SOME POSSIBLE FLOOR PANEL ARRANGEMENTS



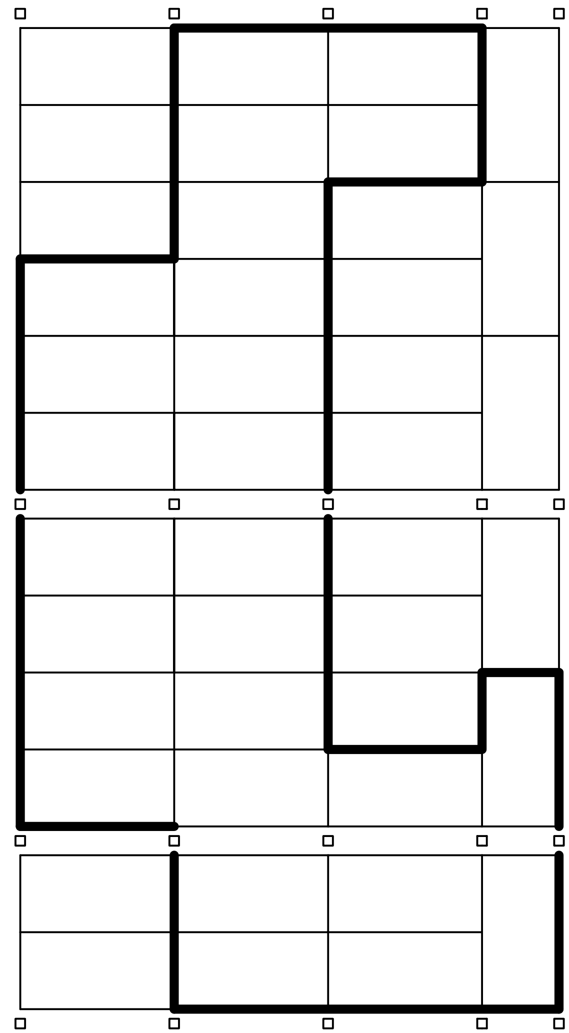
* ADDITION CONNECTIONS ARE CUSTOM

RULES OF EXPANSION



PLAN DIAGRAMS

DIAGRAM G - ENCLOSURE WALLS MAY OCCUR ANYWHERE THAT IS ALLIGNED WITH FLOOR AND CEILING PANELS



SYSTEM DERIVATION

SYSTEM IS DERIVED FROM TWO EXISTING CONSTRUCTION TYPES

SIP (STRUCTURAL INSULATED PANEL) CONSTRUCTION

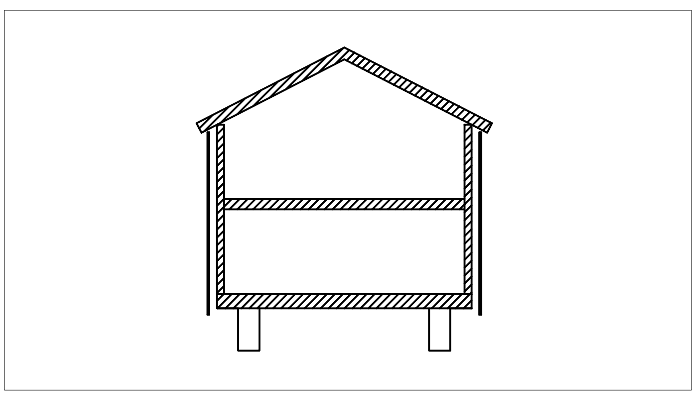
Advantages over full SIP structure

- rainscreen cavity prevents moisture sink behind cladding
- removable components, easy maintenance
- easily accessible mech/elec
- cheaper construction
- less site impact than most SIP designs
- no drilling mech/elec chases

TRADITIONAL 2X PLATFORM FRAMING

Advantages over 2x construction

- deals with moisture issues through use of ventilated cavity
- all components are easily removable and replaceable, making maintenance easy
- mech/elec spaces are easily accessible
- better insulation
- cheaper construction
- less site impact than most 2x designs

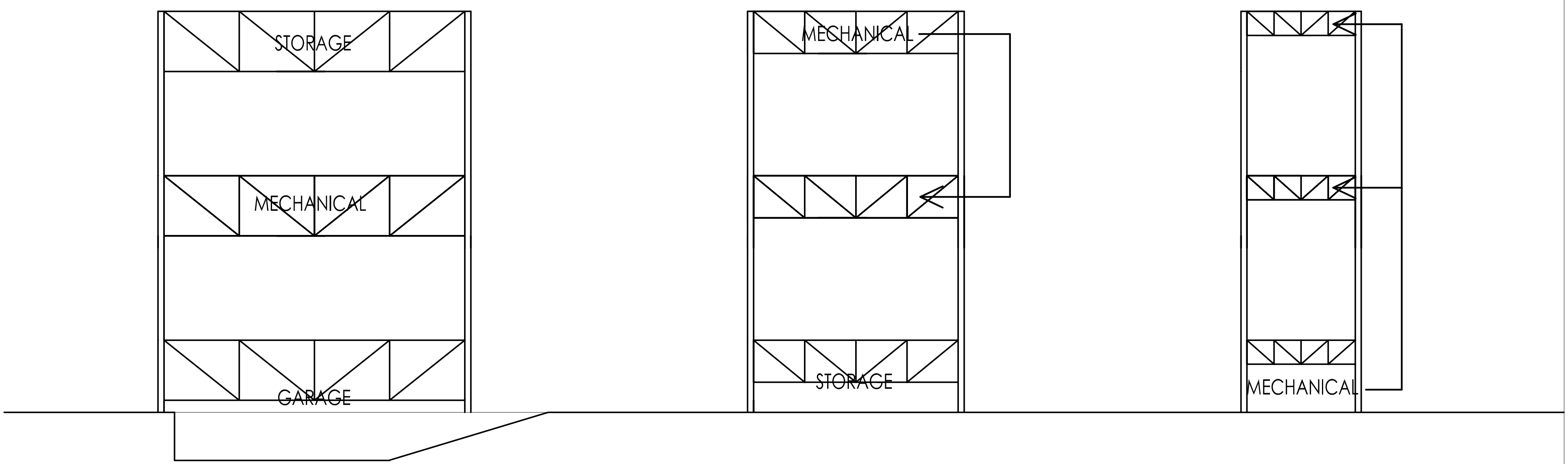


SO WHY NOT USE A STANDARD PANEL SIP SYSTEM WITH A RAINSCREEN AND NO STRUCTURAL FRAME?

- SIP SYSTEMS USE ENCLOSURE WALLS AS LOAD BEARING STRUCTURE, MAKING THIER REMOVAL DIFFICULT
- MECH/ELEC CHASES WOULD HAVE TO BE FORMED INTO INTERMEDIATE FLOOR PANELS

MARGINAL SPACES

POSSIBLE USES



25' SPAN (5' DEEP ZONE)

17' SPAN (42" DEEP ZONE)

9' SPAN (24" DEEP ZONE)

*BOTTOM TWO MARGINAL ZONES MAY BE MADE INTERIOR SPACE

ECONOMY

- PREFAB COMPONENTS REDUCE LABOR COSTS

- LIMITED SET OF STANDARD COMPONENTS REDUCE COSTLY CHOICES

- STANDARD PANEL SIZE IS 4'x 8' - DISTRIBUTOR OF PLYWOOD AND POLYSTYRENE BOARDS DOES THE CUTTING FOR FREE!

- DEMOUNTABLE COMPONENTS FOR EASY MAINTENANCE AND REPLACEMENT

- EASILY ACCESSIBLE MECH/ELEC SPACES REDUCE EXPENSIVE MAINTENANCE

- PROTECTED AND VENTILATED STRUCTURE HAS A LONG LIFETIME AND REQUIRES MINIMAL MAINTENANCE

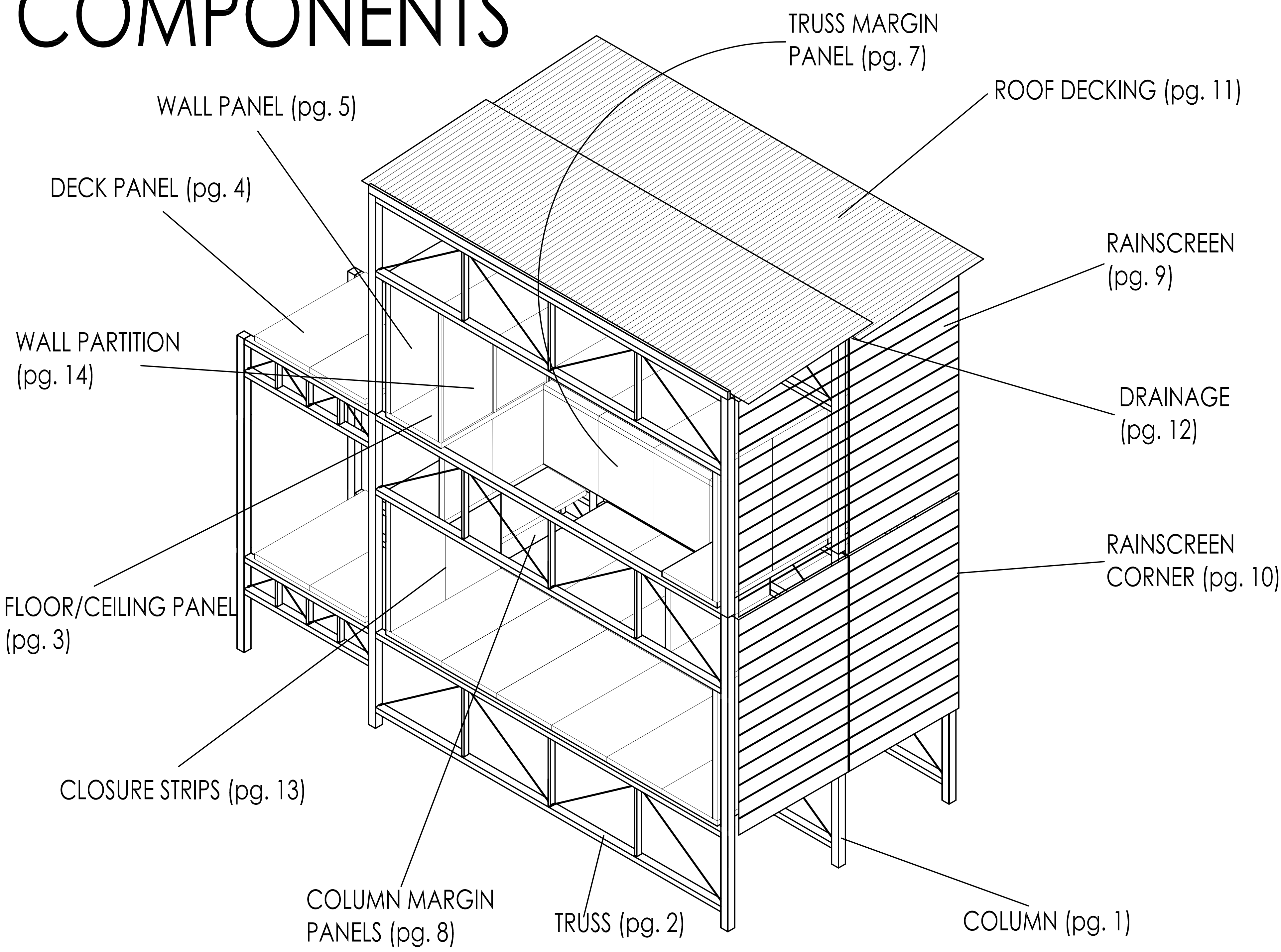
- LOW IMPACT OF HOUSE ON SITE (EROSION, GROUND DISTURBANCE, ETC...)

- LOW IMPACT OF SITE ON HOUSE (FLOODING, ROT, ETC...)

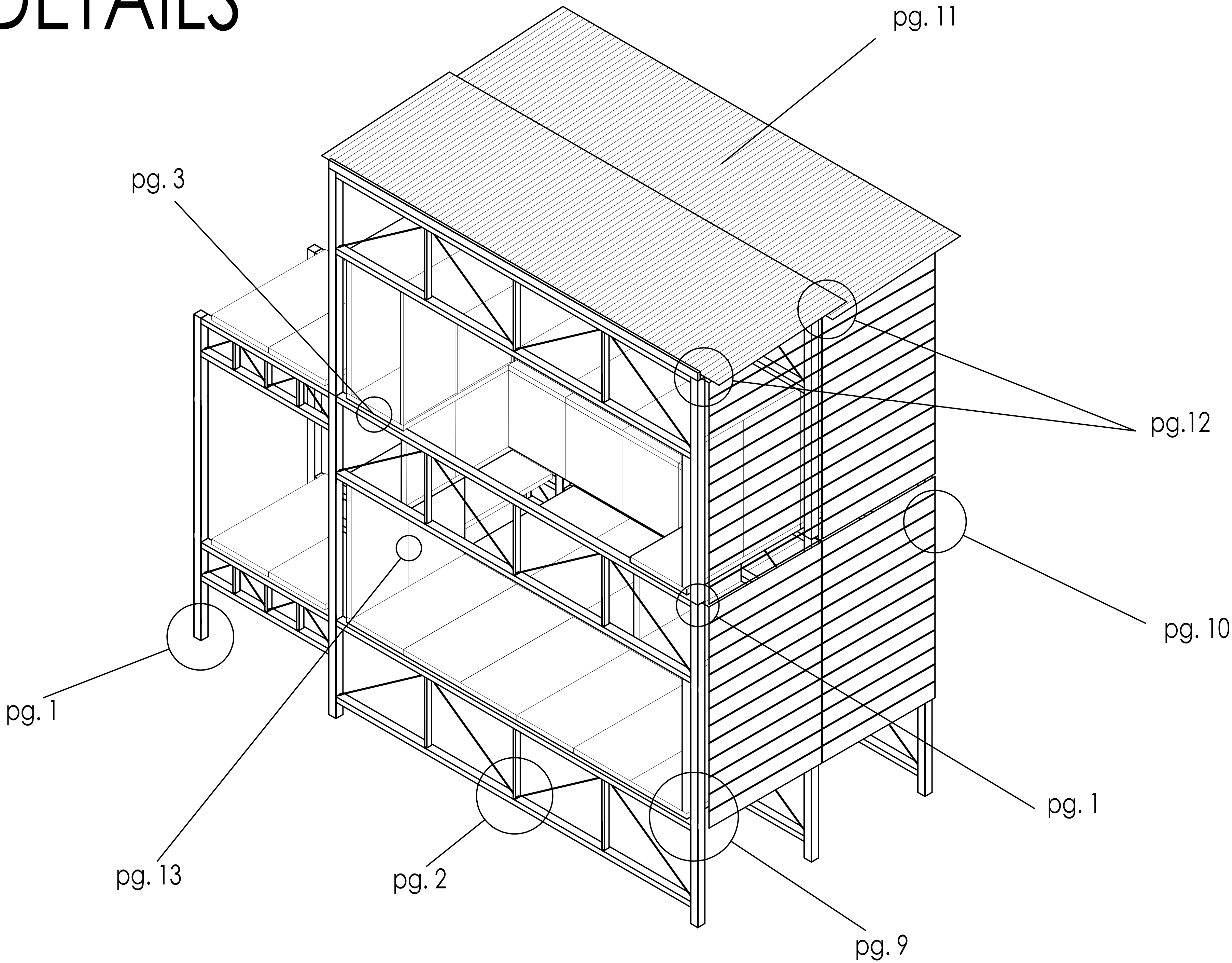
FLEXIBILITY

- TACTILE COMPONENTS AND SPACES MAY BE ARRANGED TO INDIVIDUAL PREFERENCE
- MORE INTIMATE DETAILS SUCH AS DOORS, WINDOWS, AND FINISHES ARE CUSTOM
- RAINSCREEN PANELS MAY BE GLASS OR WOOD AND MAY BE ARRANGED HORIZONTALLY IN ANY ORDER
- 3 DIFFERNT STRUCTURAL SPANS
- 1-2 FLOORS
- ENCLOSURE WALLS MAY PULL AWAY FROM BOUNDARIES SET BY STRUCTURE

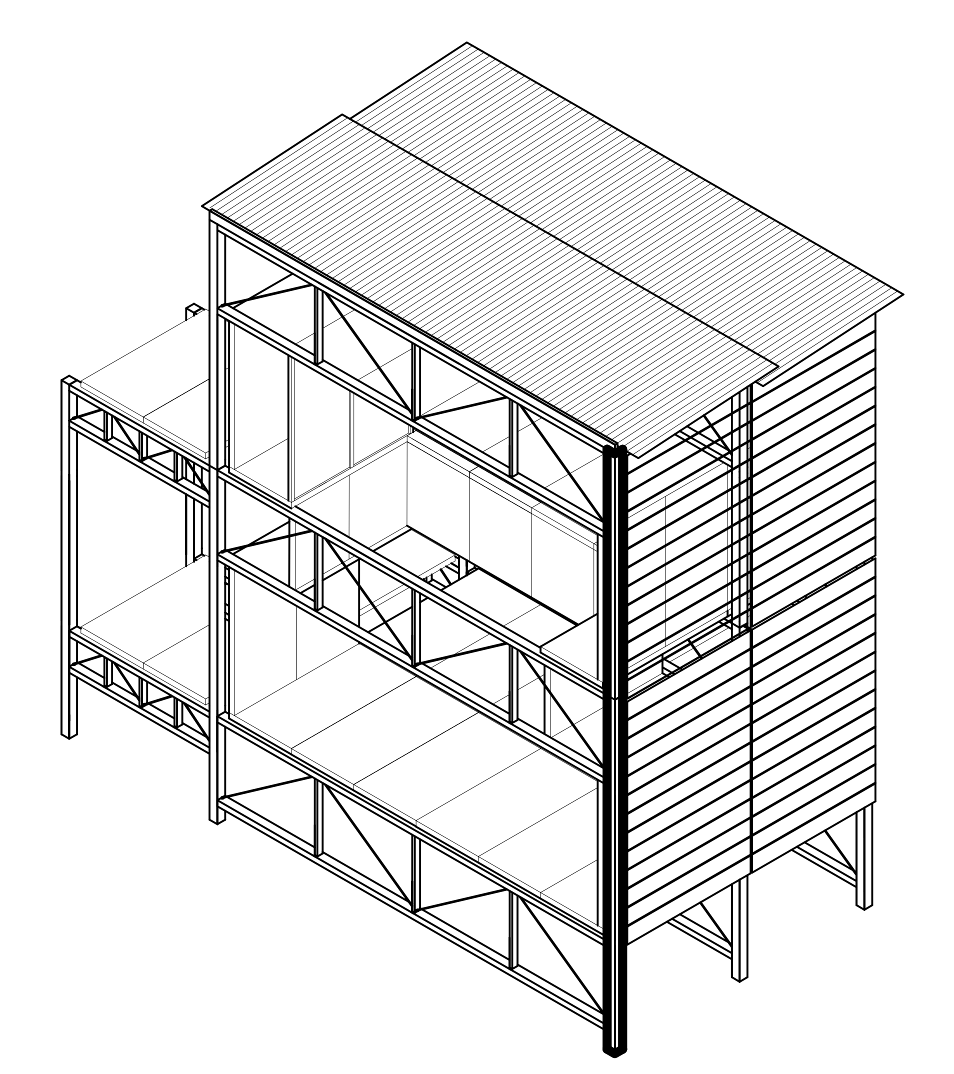
COMPONENTS

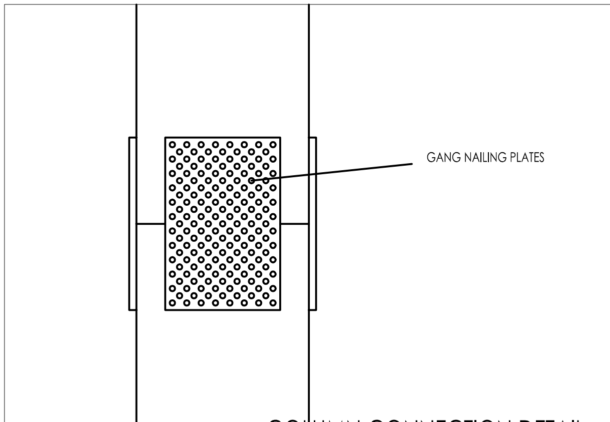

TRUSS MARGIN
PANEL (pg. 7)
ROOF DECKING (pg. 11)
WALL PANEL (pg. 5)
DECK PANEL (pg. 4)
RAINSCREEN
(pg. 9)
WALL PARTITION
(pg. 14)
DRAINAGE
(pg. 12)
RAINSCREEN
CORNER (pg. 10)
FLOOR/CEILING PANEL
(pg. 3)
CLOSURE STRIPS (pg. 13)
COLUMN MARGIN
PANELS (pg. 8)
TRUSS (pg. 2)
COLUMN (pg. 1)

DETAILS

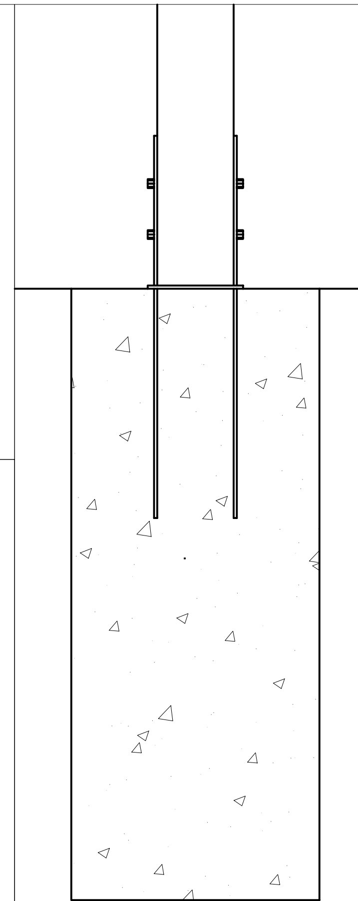


COLUMN

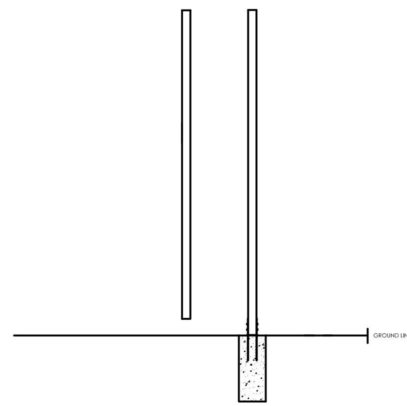




COLUMN CONNECTION DETAIL



FOOTING DETAIL



GROUND FLOOR AND SECOND FLOOR COLUMNS

- ALL COLUMNS ARE 6x6 GLU LAMS

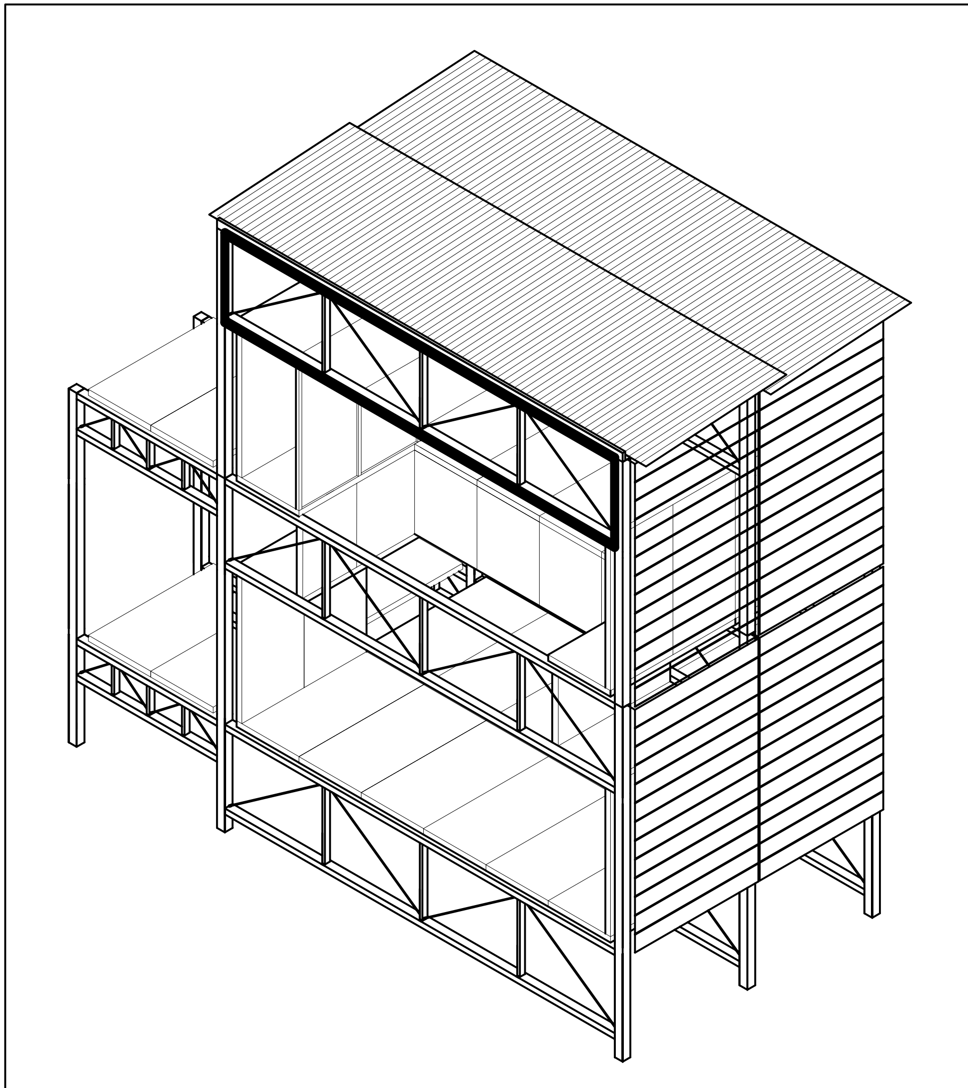
- GROUND FLOOR COLUMN IS 19'- 8"

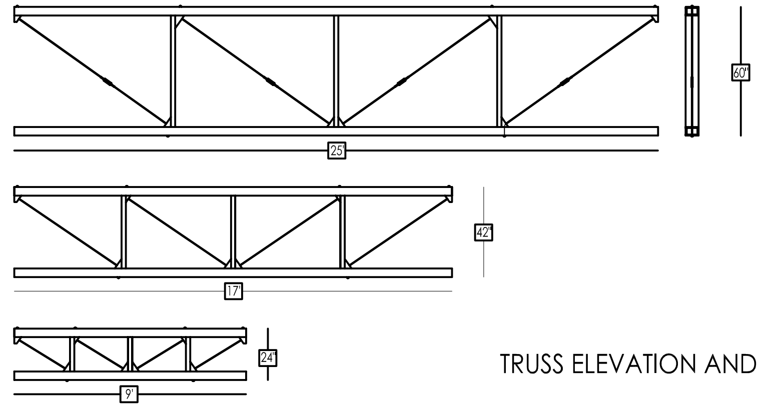
- SECOND FLOOR COLUMN IS 18'- 8"

- COLUMN IS SET IN CONCRETE USING A STEEL FOOTING BRACKET WITH A GROUND PLATE

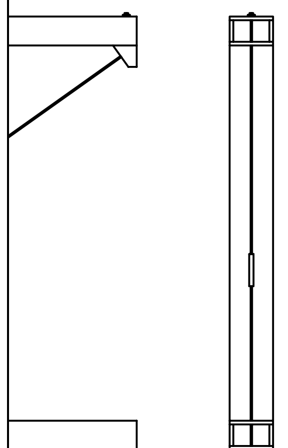
- MAY SUPPORT UP TO 2 STOREYS - 3+ IF COMUMNS ARE MADE THICKER

TRUSS

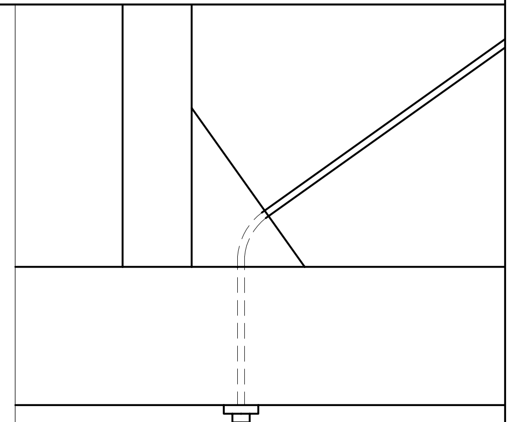




TRUSS ELEVATION AND SECTION



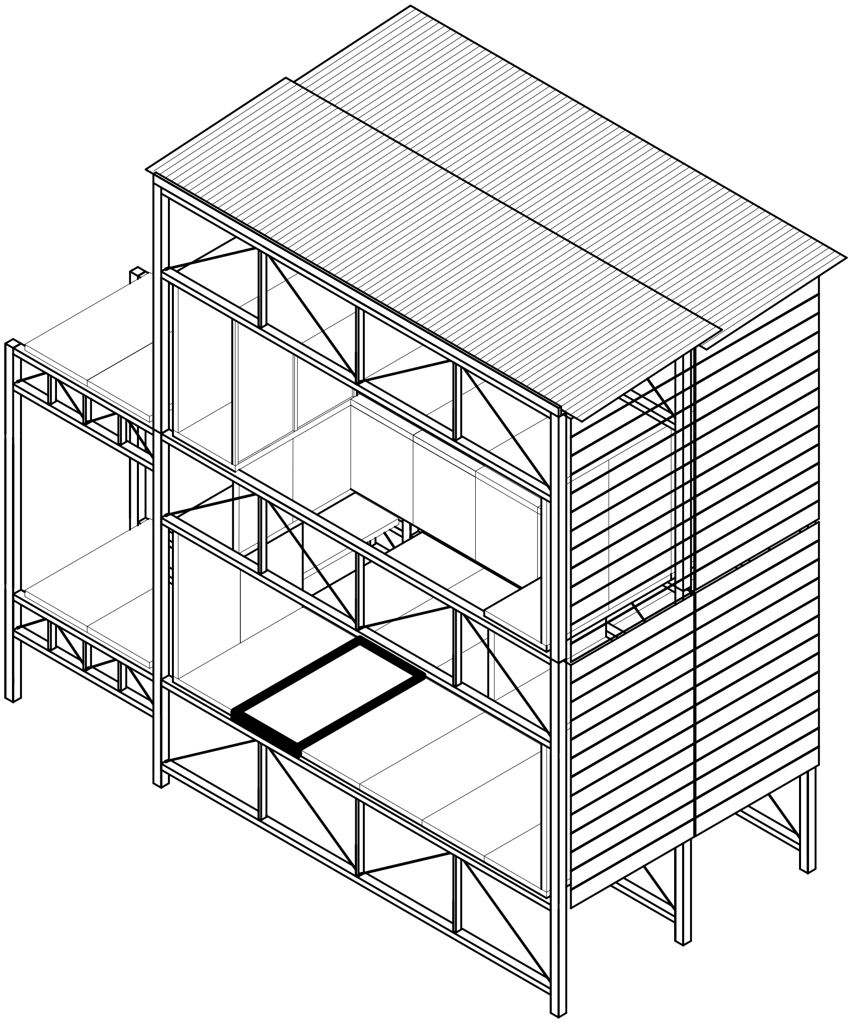
TRUSS SECTION DETAIL



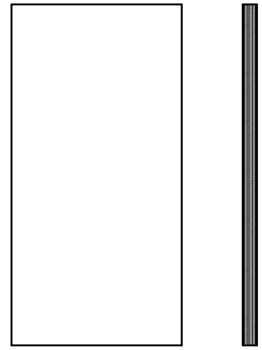
CABLE CONNECTION DETAIL

- THE SYSTEM HAS THREE AVAILABLE TRUSS SIZES WITH SPANS OF 25', 17', AND 9'
- ALL TRUSSES ARE DESIGNED TO HANDLE AN ASSEMBLY LOAD OF 100PSF
- CONSTRUCTED OF BOX BEAMS AND STEEL CABLES
- 4"x 6" TOP AND BOTTOM CHORDS
- 2"x 6" WEB COMPRESSION MEMBERS

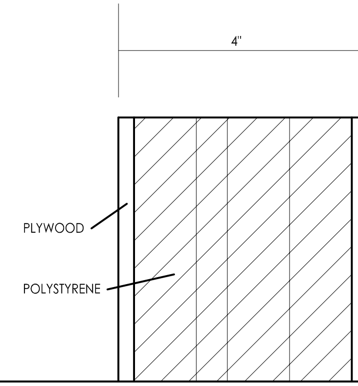
FLOOR/CEILING PANEL



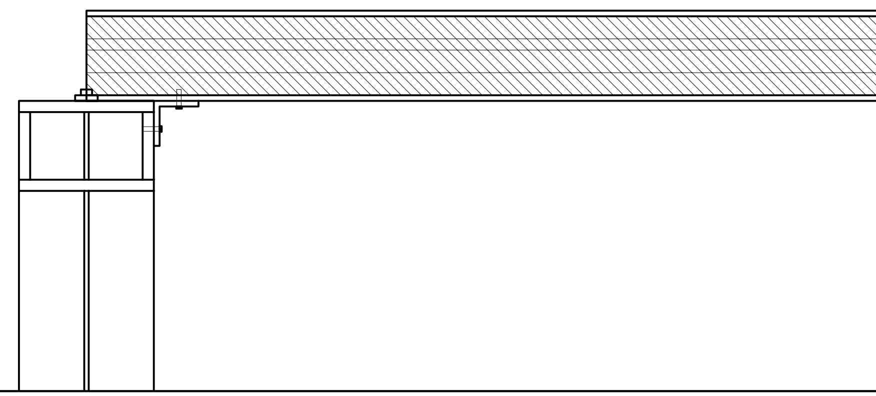
PANEL PLAN AND SECTION



PANEL SECTION DETAIL

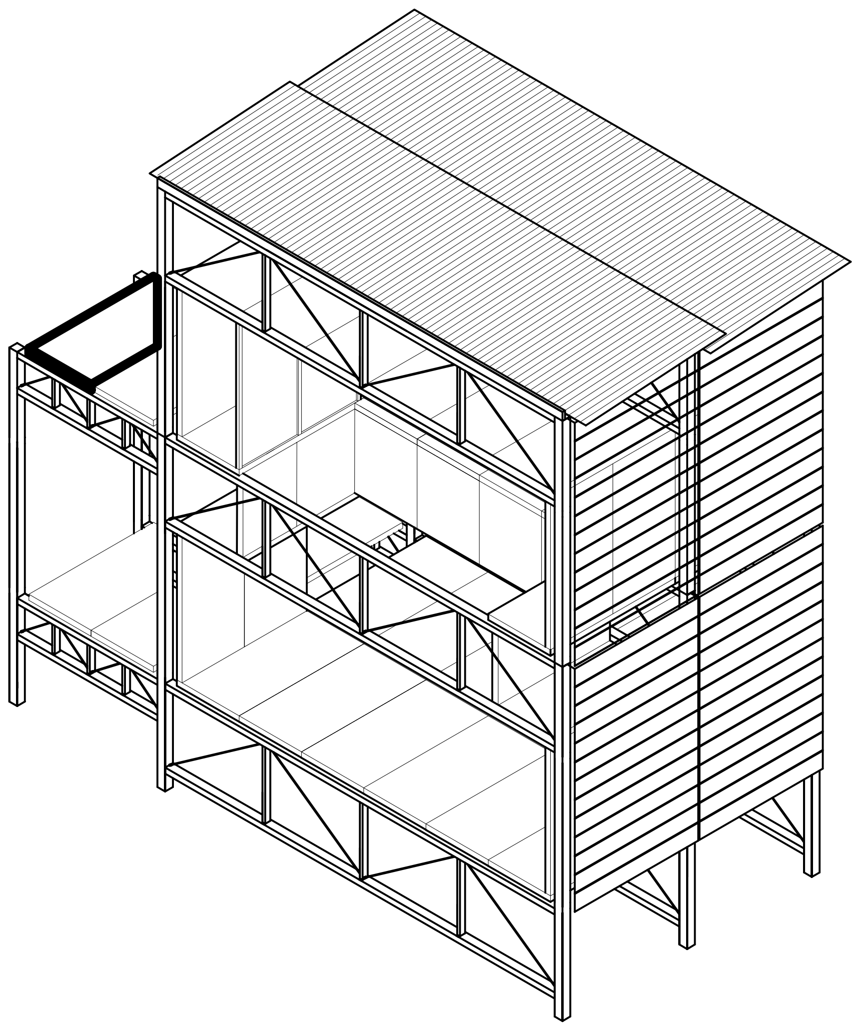


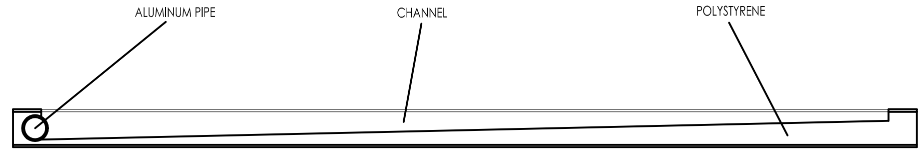
PANEL CONNECTION DETAIL



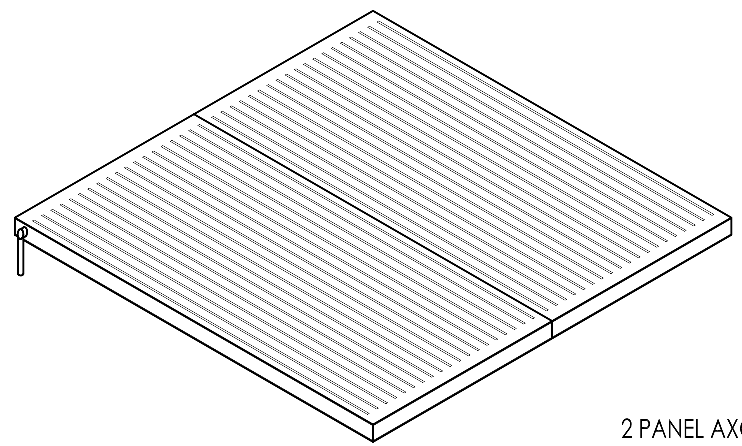
- ALL FLOOR/CEILING PANELS ARE 4'x 8'x 4"
- CONSTRUCTED OF POLYSTYRENE BOARDS AND 1/2" PLYWOOD (STRESS-SKIN)
- CONNECTED DIRECTLY TO TRUSS CHORDS

DECK PANEL





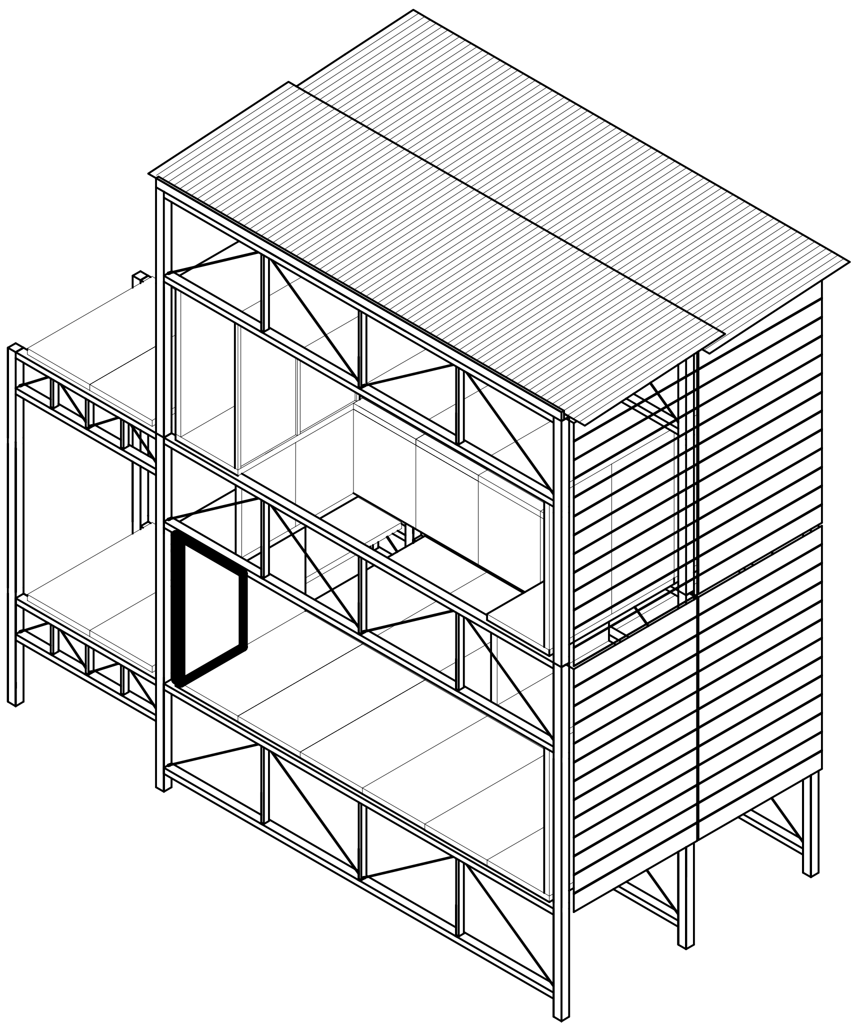
PANEL SECTION

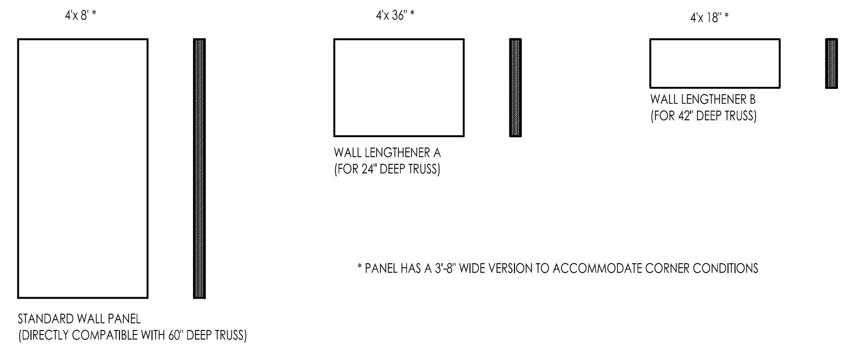


2 PANEL AXON

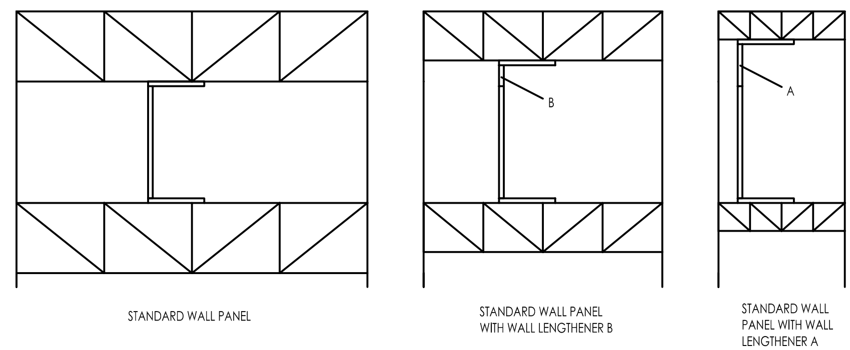
- PANEL HAS ITS OWN DRAINAGE SYSTEM AND MAY BE LEFT EXPOSED
- CONSTRUCTED OF 1/4" PLYWOOD AND POLYSTYRENE BOARDS
- 1/4" WIDE LENGTHWISE CHANNELS DRAIN TO ALUMINUM PIPE

WALL PANEL





WALL PANEL ELEVATIONS AND SECTIONS



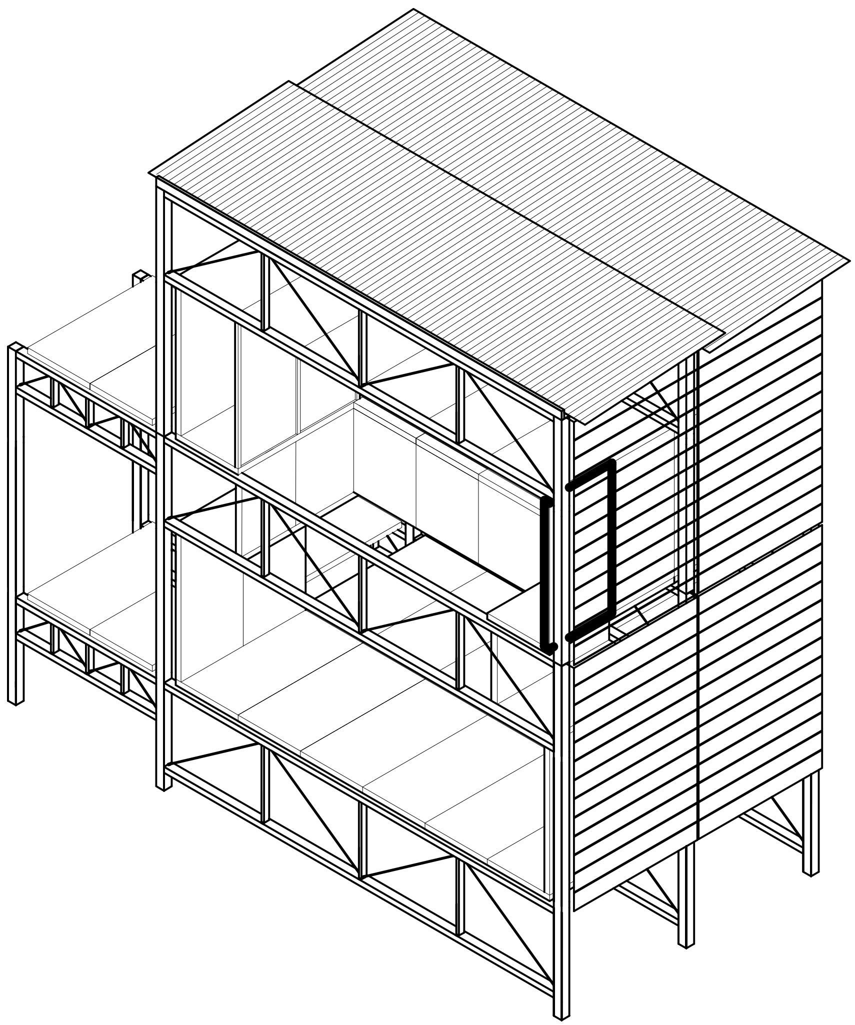
- ENCLOSURE WALLS ACT AS INSULATION

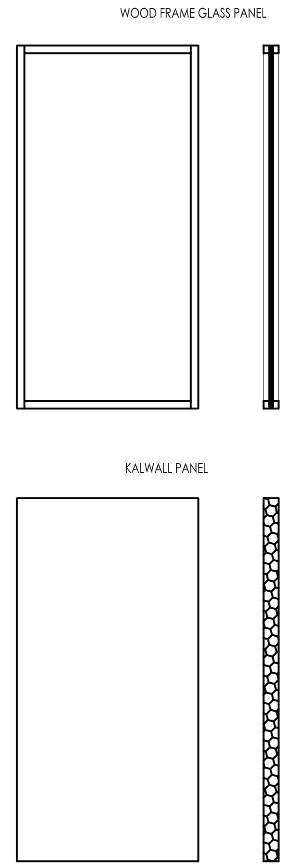
- STANDARD WALL PANEL IS COMPATIBLE WITH 25' TRUSS WITH WALL LENGTHENERS USED TO ACCOMODATE SHORTER TRUSSES

- CONSTRUCTED OF 2.75" CLOSED CELL FOAM FACED WITH WITH 1/4" PLYWOOD OR LEFT OPEN TO AIR

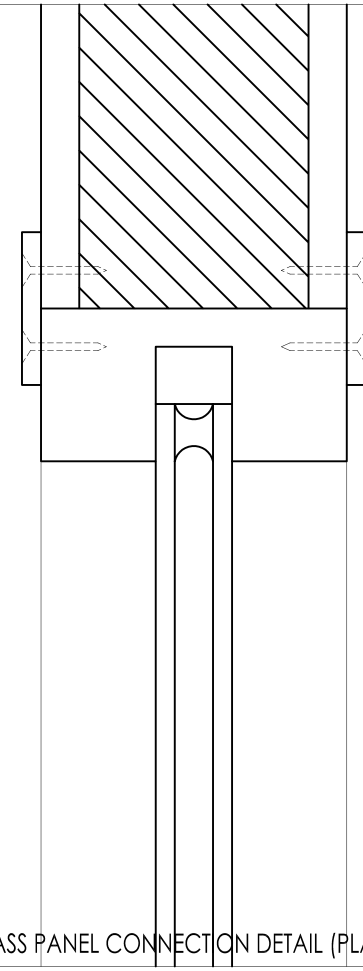
- PLASTERBOARD INTERIOR FINISH

GLASS WALL PANEL





TRANSPARENT AND TRANSLEUCENT PANELS

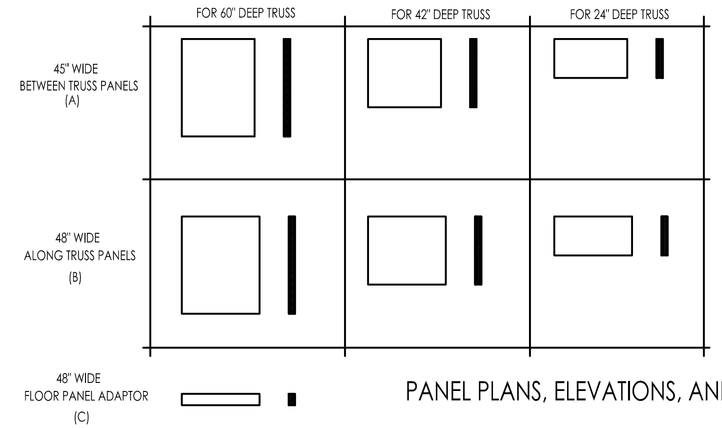


GLASS PANEL CONNECTION DETAIL (PLAN)

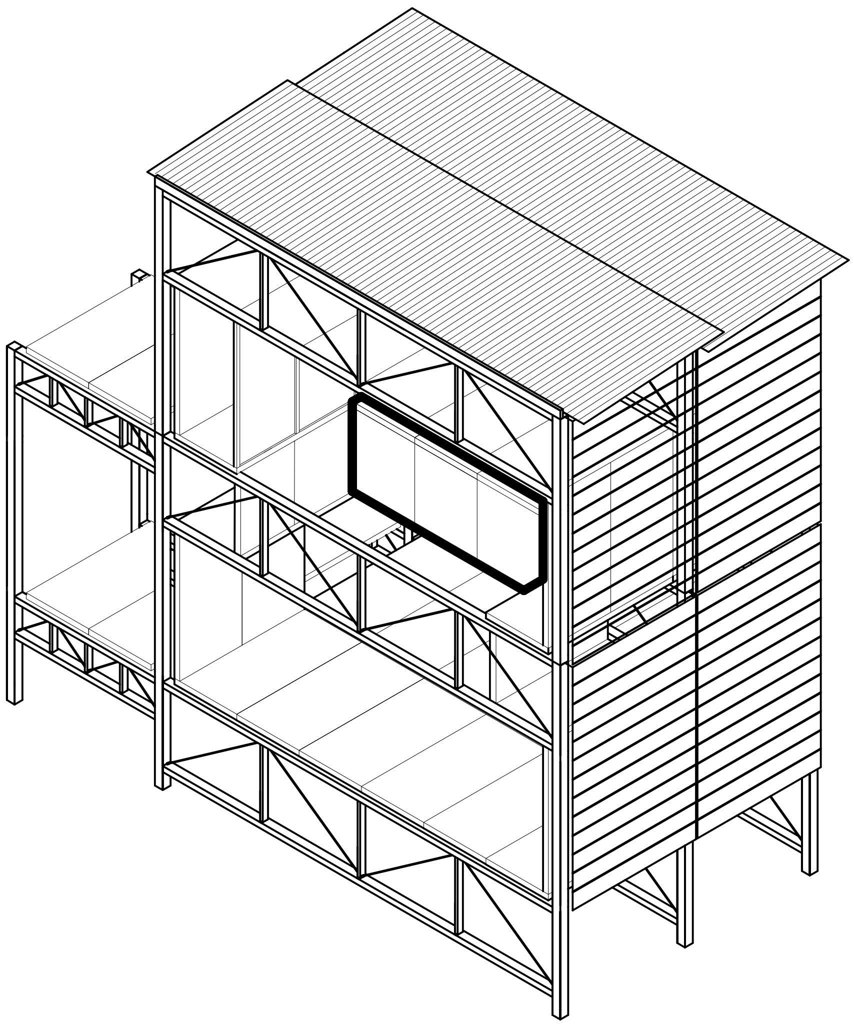
- LIGHT ADMITTING PANELS MAY REPLACE ANY WALL OR CEILING PANELS

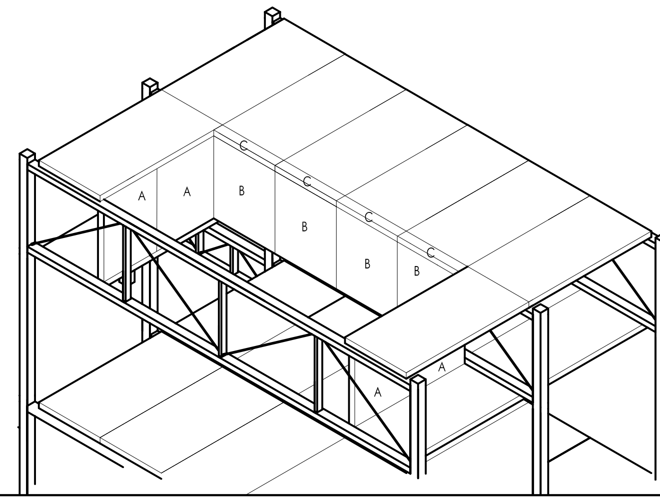
- GLASS PANELS PROVIDE FLOOR TO CEILING WINDOWS

TRUSS ZONE PANELS



PANEL PLANS, ELEVATIONS, AND SECTIONS

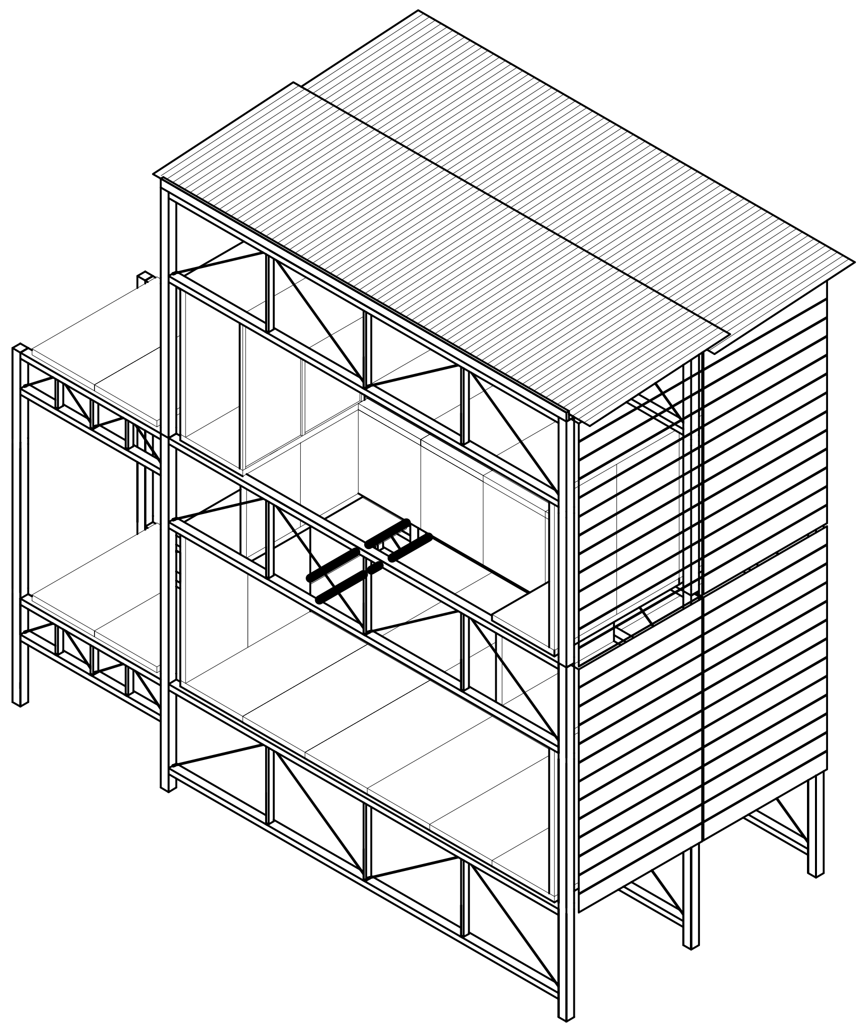


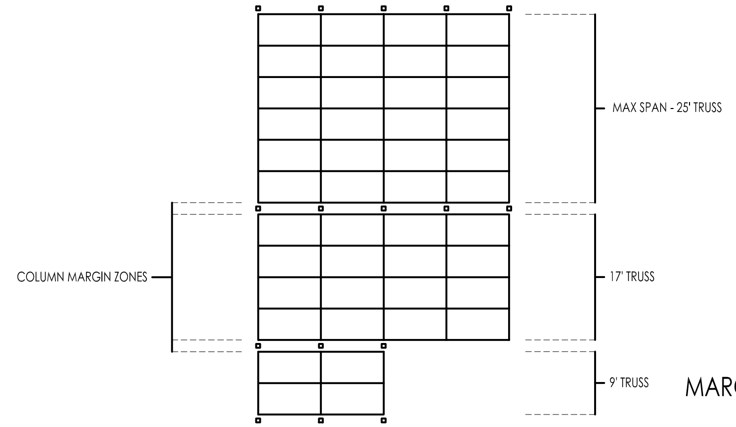


- ALLOWS SPATIAL TRANSITION THROUGH TRUSS ZONE

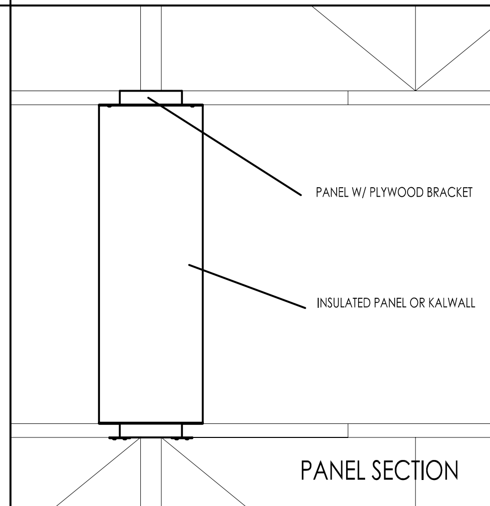
- ALLOWS DOUBLE HEIGHT SPACES TO OCCUR WITHOUT INTERRUPTING INSULATION

COLUMN ZONE PANELS

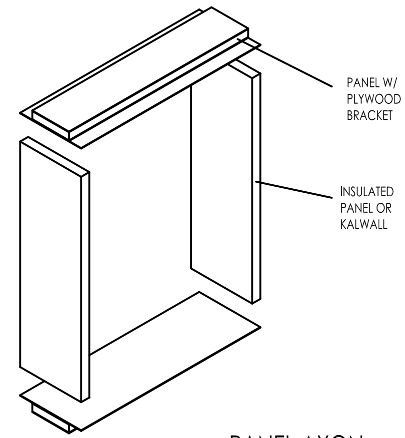




MARGIN ZONES



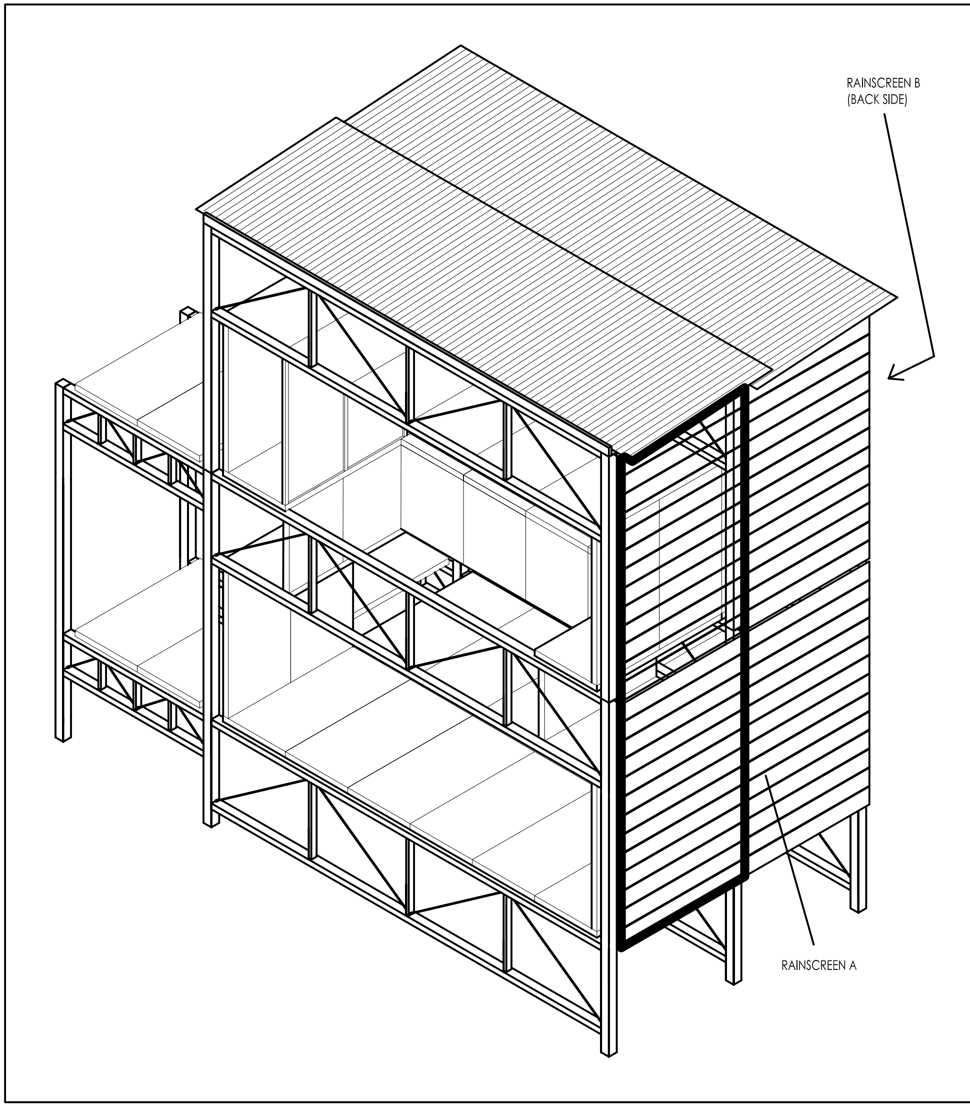
PANEL SECTION

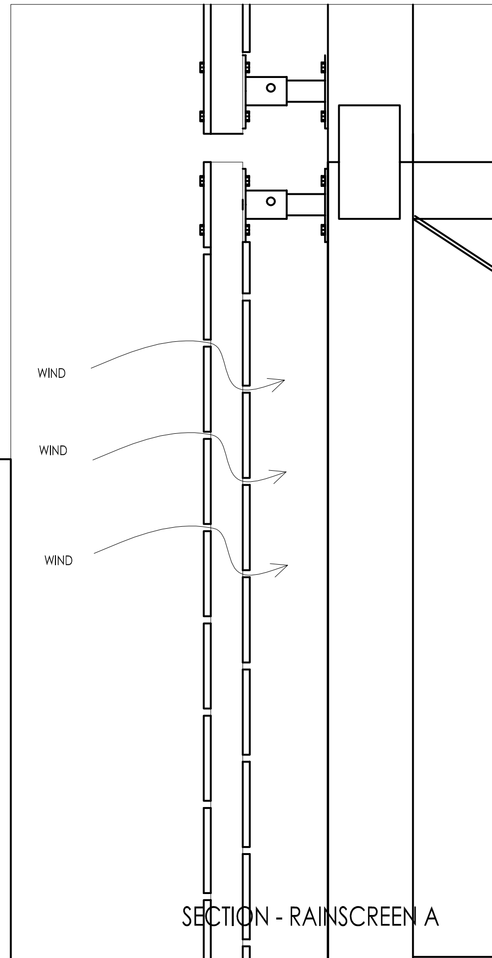


PANEL AXON

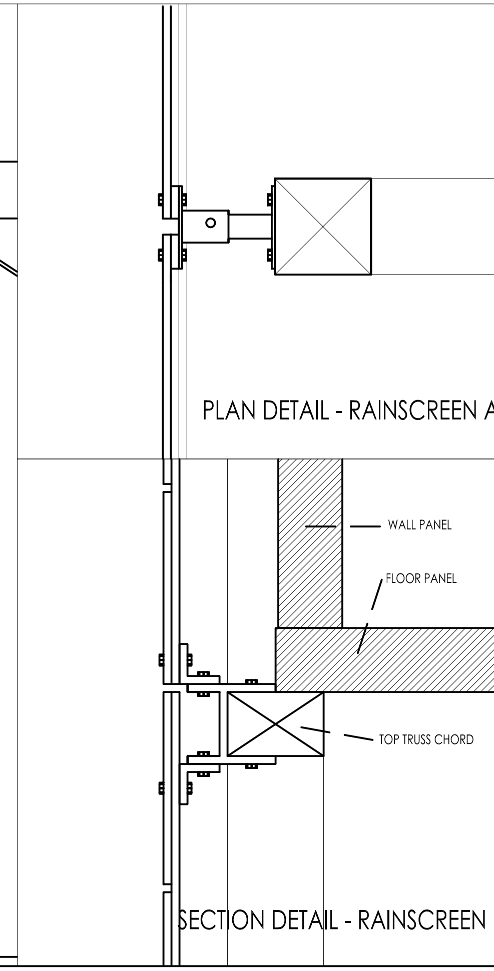
- ALLOWS SPATIAL TRANSITION THROUGH COLUMN ZONE WITHOUT INTERRUPTING INSULATION

DOUBLE RAINSCREEN





SECTION - RAINSCREEN A

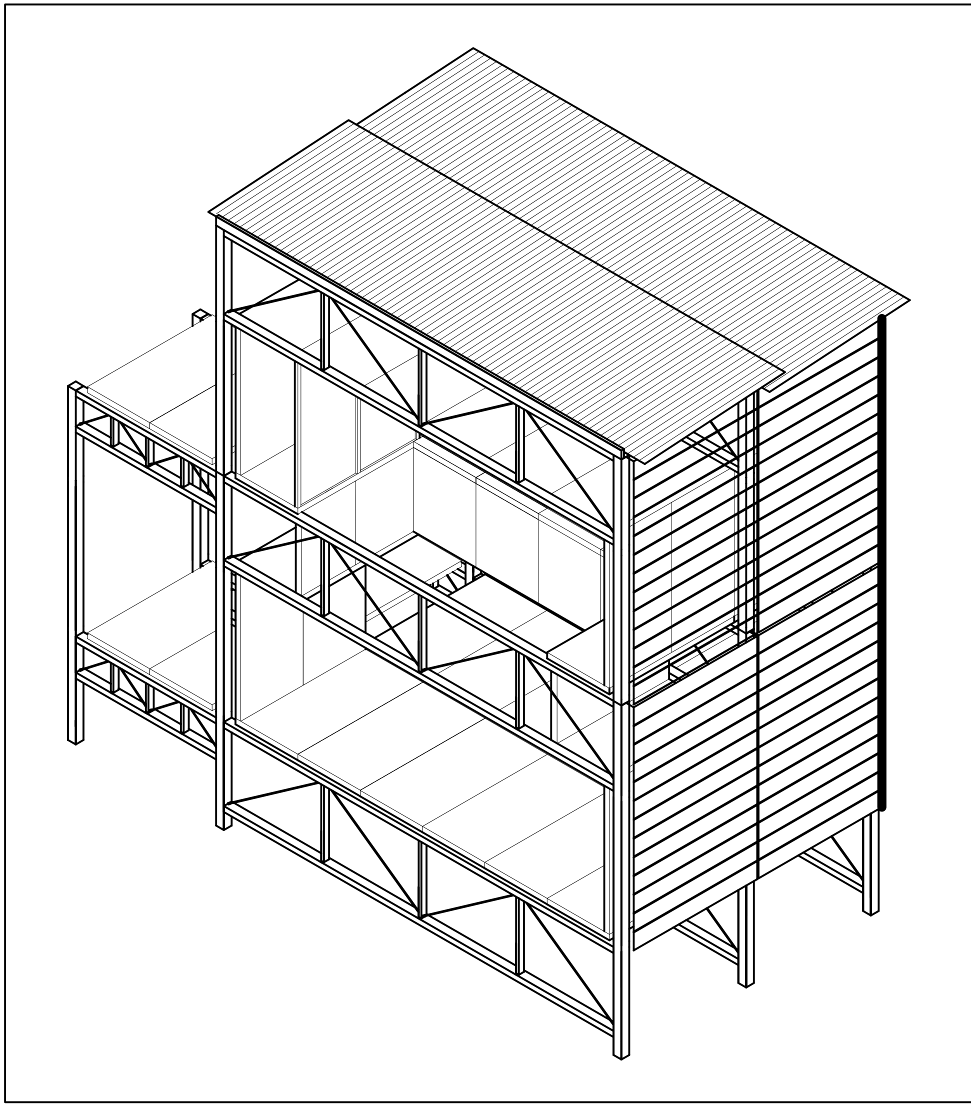


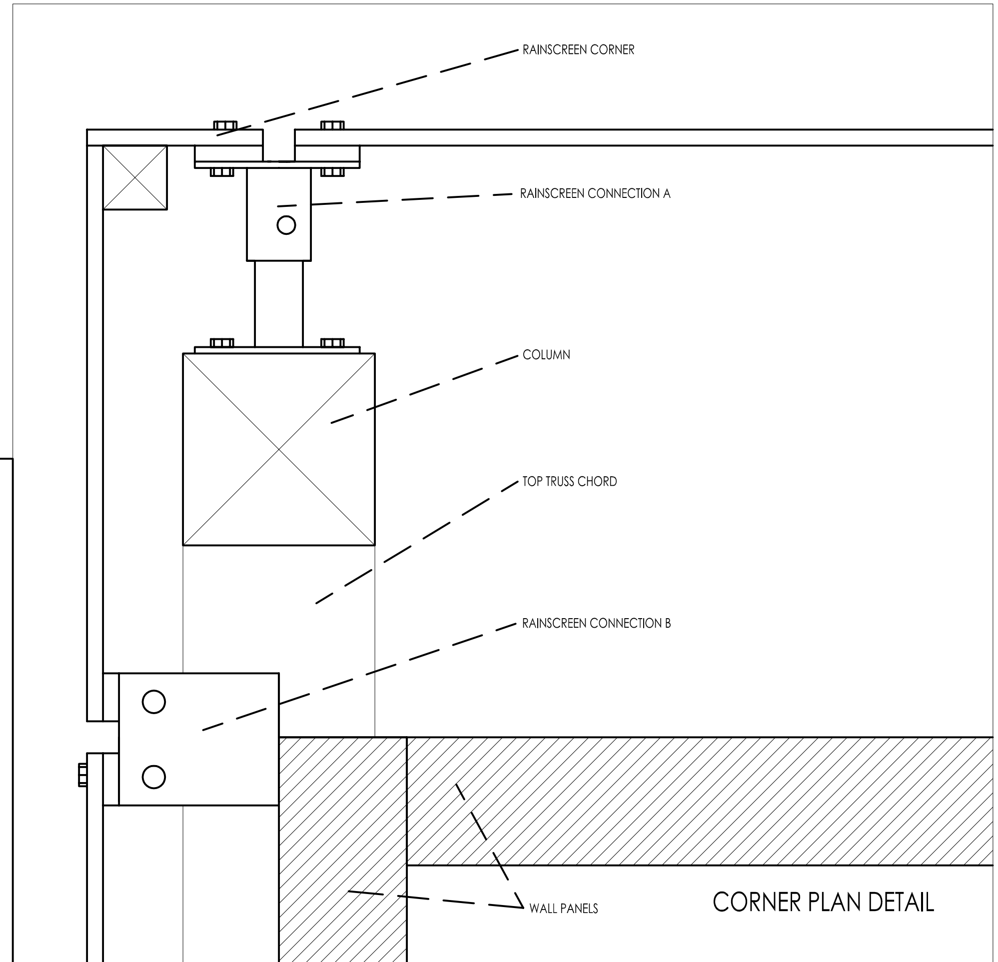
PLAN DETAIL - RAINSCREEN A

SECTION DETAIL - RAINSCREEN B

- RAINSCREEN MAY BE CONSTRUCTED WITH ANY COMBINATION OF 6" WOOD PANELS OR 12" GLASS PANELS
- RAINSCREEN A HAS A CONNECTION CONDITION THAT IS PERPINDICULAR TO TRUSSES (CONNECTION A)
- RAIN SCREEN B HAS A CONNECTION CONDITION THAT IS PARALLEL TO TRUSSES (CONNECTION B)
- EXTENDED LENGTH RAINSCREEN USED FOR ROOF EDGES SEE DRAINAGE - PG.

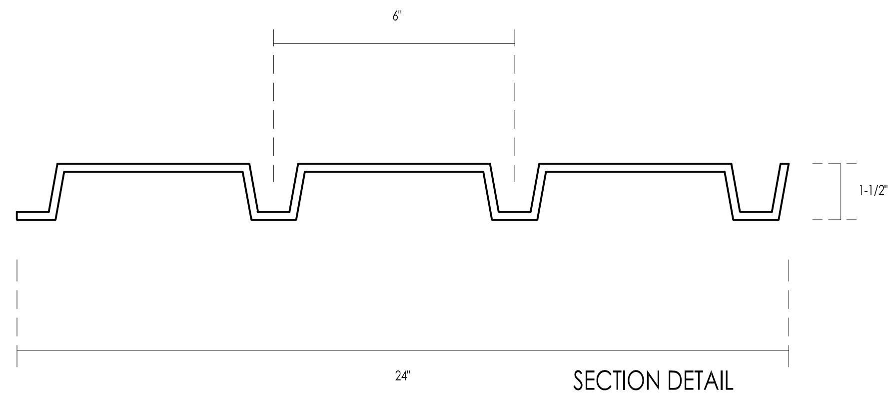
RAINSCREEN CORNER

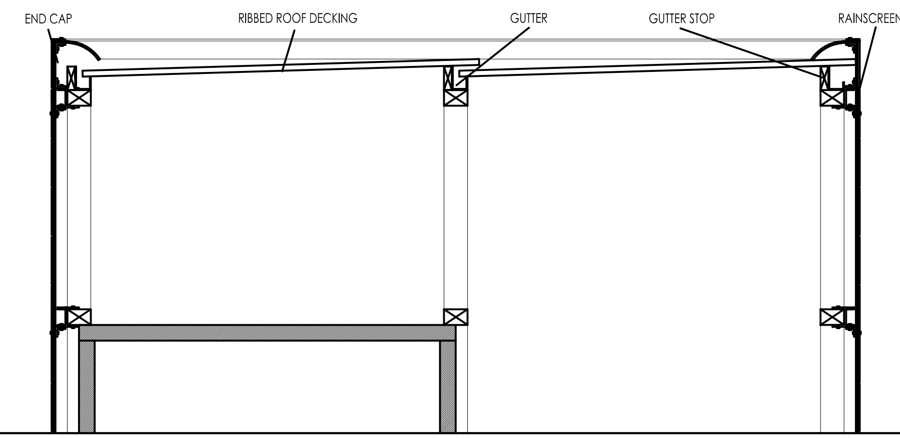


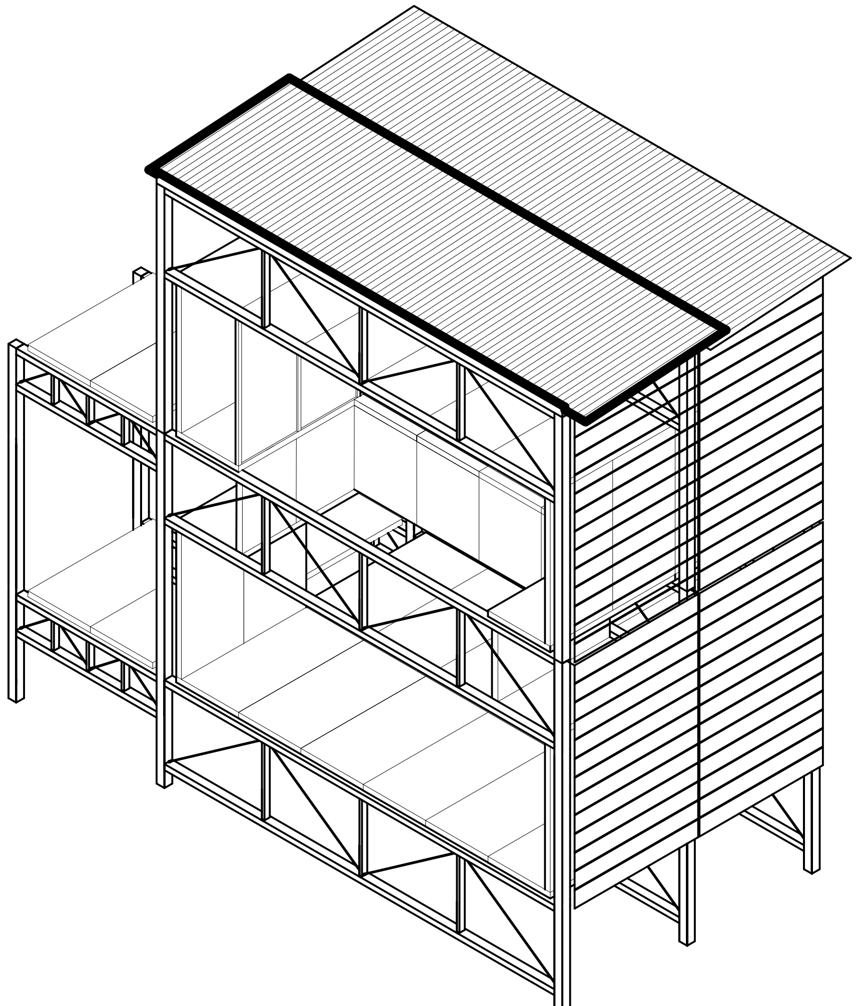


- PROTECTS CORNER STRUCTURAL ELEMENTS
- ATTACHES DIRECTLY TO RAINSCREEN BRACKETS
- ANOTHER ATTACHMENT AVAILABLE FOR MARGINAL ZONES

ROOF DECKING

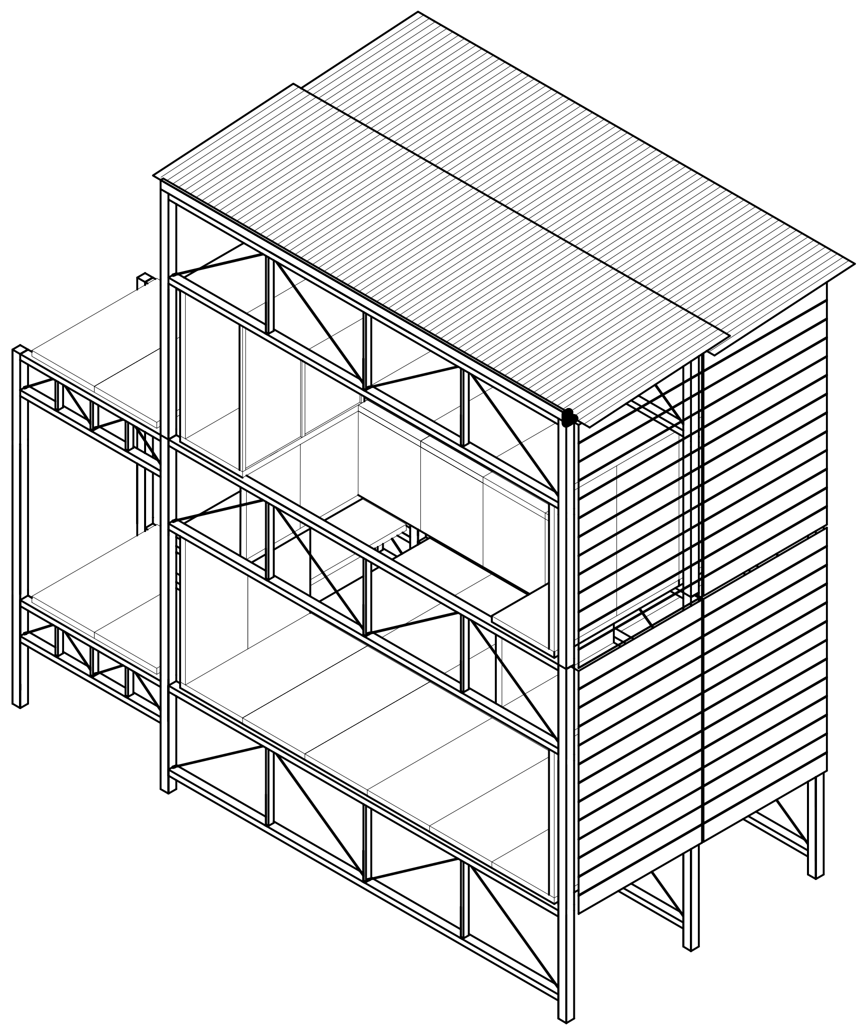


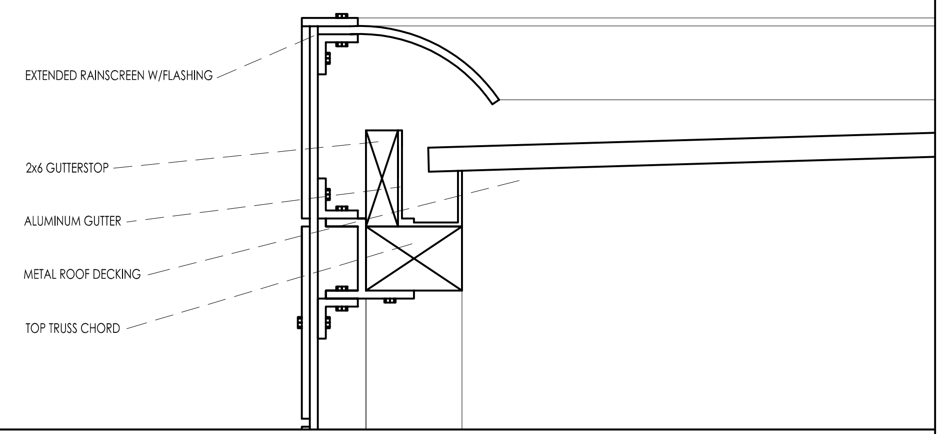


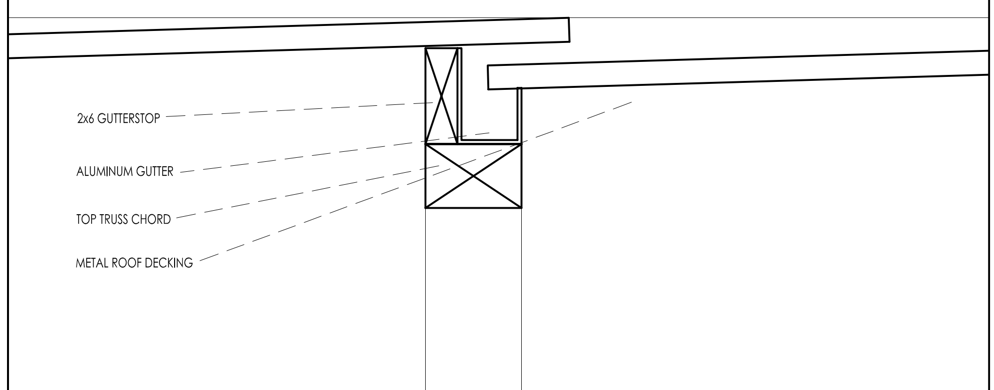


- EACH STANDING SEAM ROOF PANEL IS 8'-6'' x 2'
- DECKING DIMENSIONS ALLOW A MAX SPAN OF 9'

DRAINAGE SYSTEM

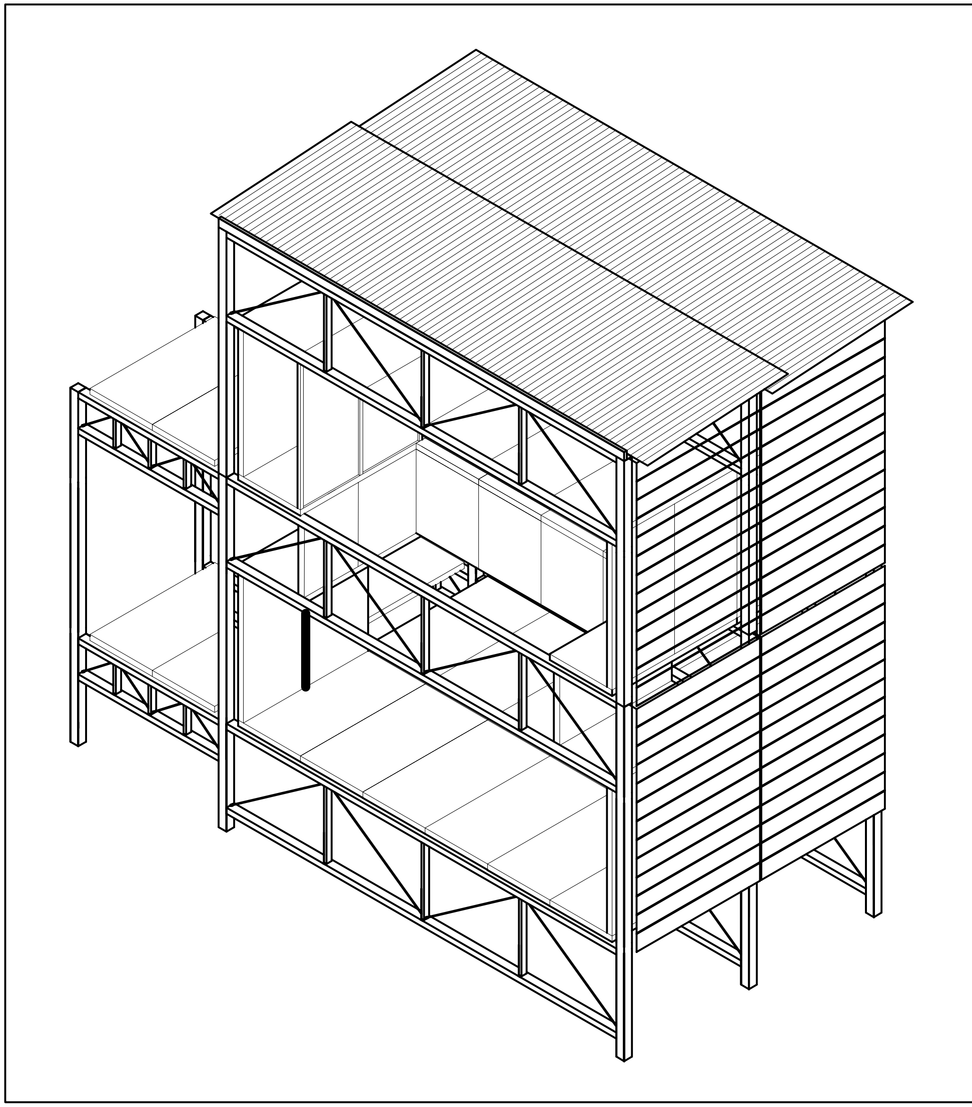


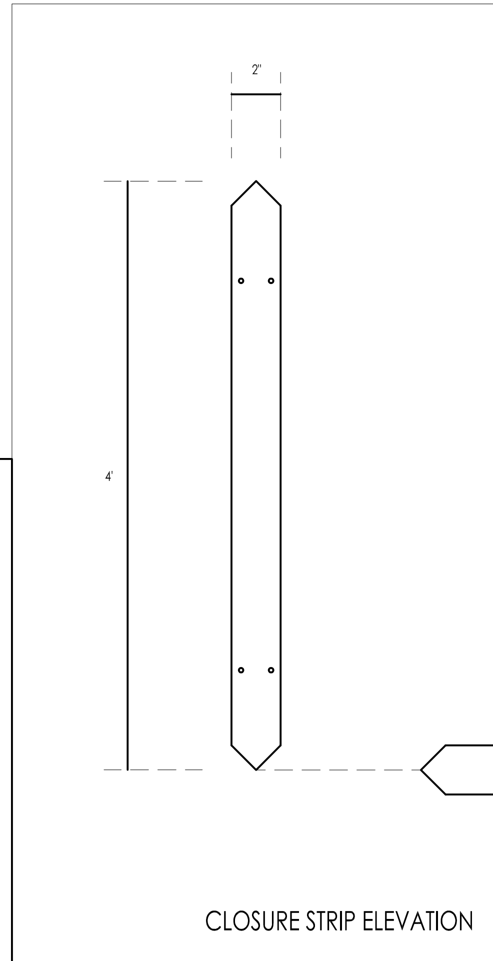




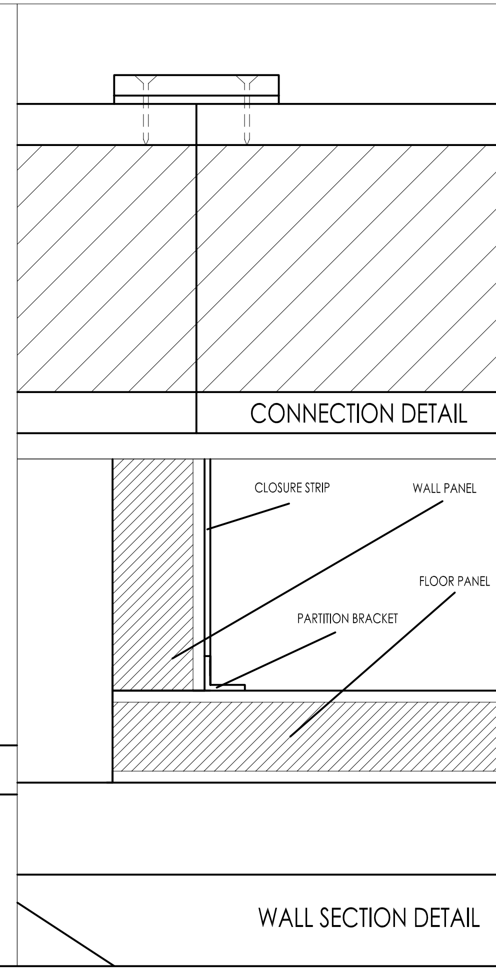
- 2x6 GUTTER STOP HOLDS ALUMINUM GUTTER IN PLACE AND SUPPORTS ADJACENT ROOF DECKING
- WATER IS DISCHARGED THROUGH A DRAINPIPE THAT RUNS ALONG THE COLUMN, BEHIND THE RAINSCREEN.
- EXTRA DEEP GUTTER ACCOMODATES THE STANDING WATER CONDITION THAT ACCOMPANIES A GUTTER WITH UNLIMITED EXPANSION

PANEL CLOSURE





CLOSURE STRIP ELEVATION



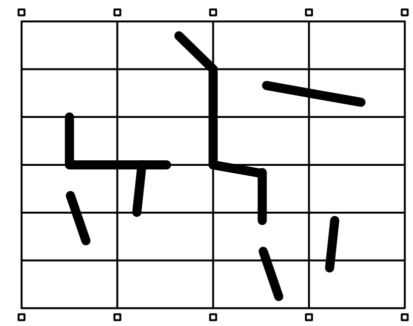
CONNECTION DETAIL

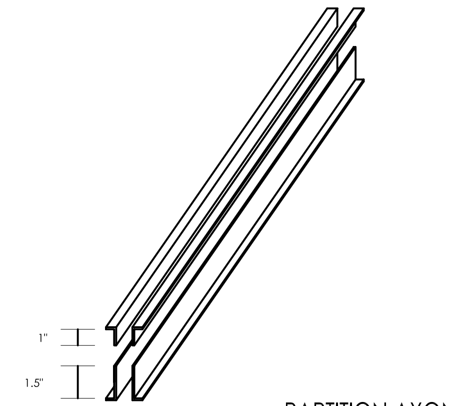
WALL SECTION DETAIL

- 1/4" ALUMINUM STRIPS USED TO CLOSE INTERIOR AND EXTERIOR SEAMS

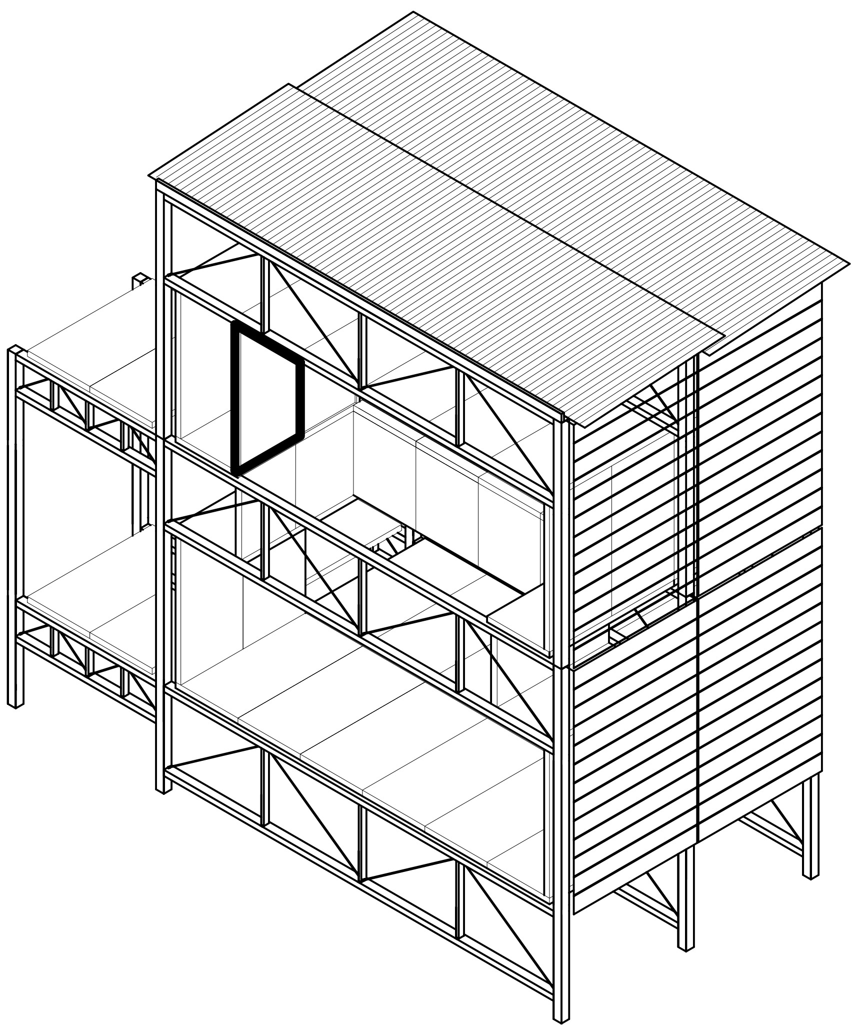
- DIFFERENT LENGTH STRIPS ACCOMODATE DIFFERENT PANEL SIZES

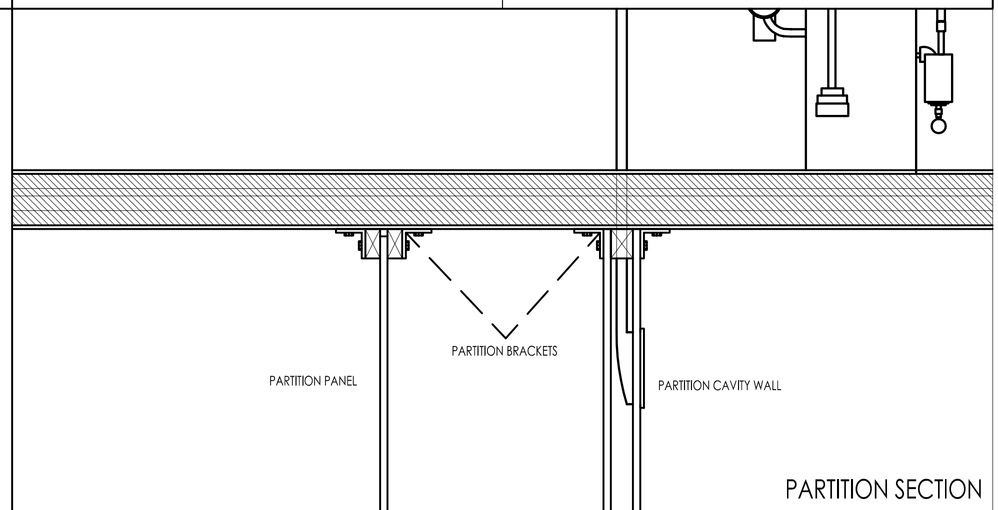
WALL BRACKETS


PARTITION PLAN



PARTITION AXON

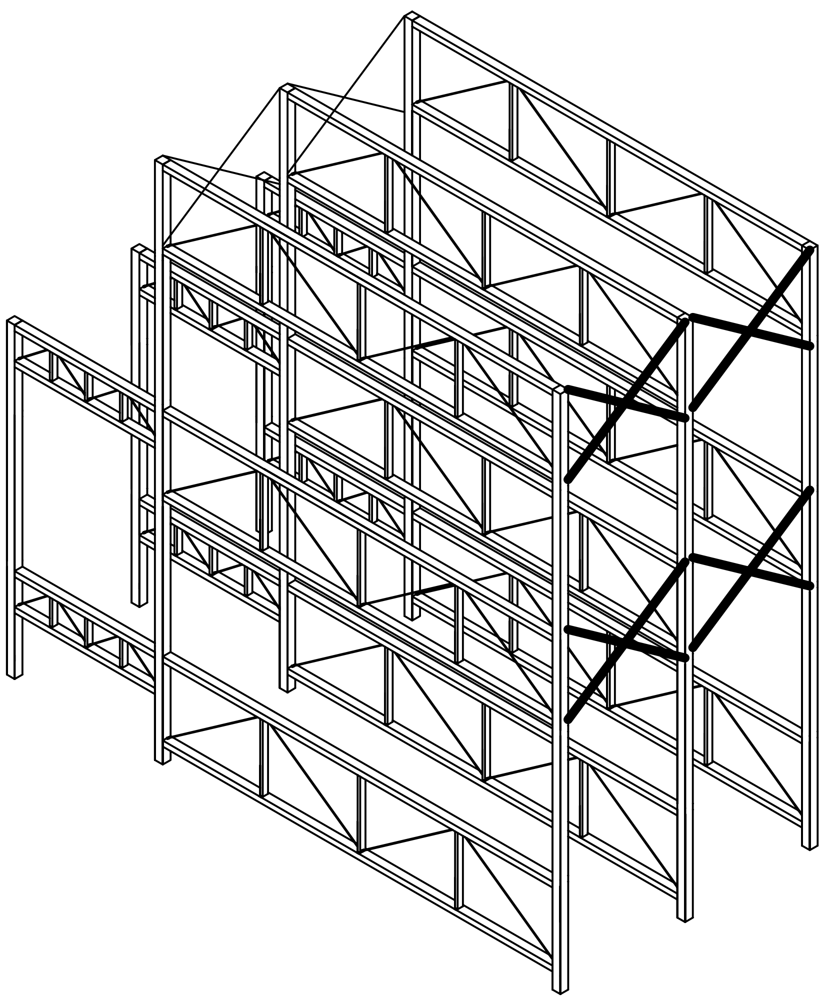


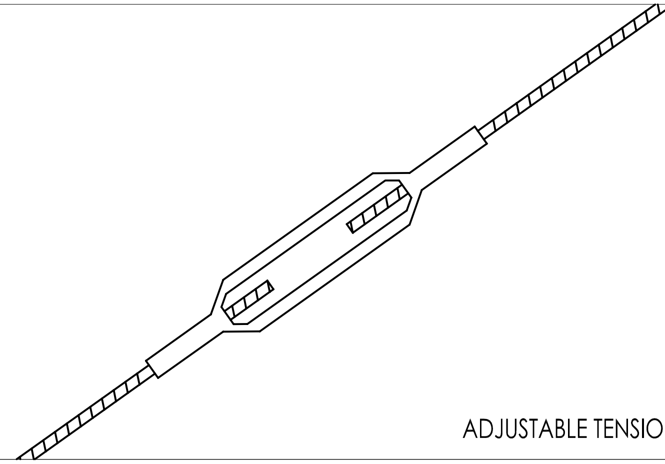


PARTITION SECTION

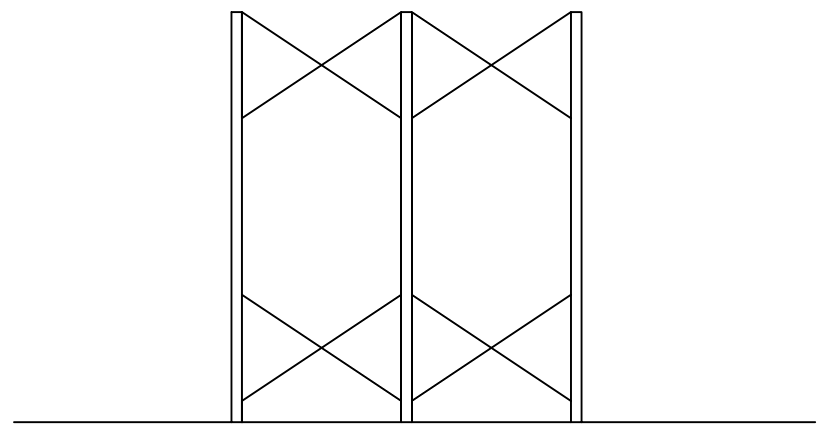
- BRACKETS MAY SUPPORT ANY THICKNESS 4'x8' PARTITION
- PARTITIONS MAY BE PANEL OR CAVITY WALL
- BRACKETS ARE 4' LONG, ALUMINUM, ANGLE GAUGE 1/8"
- BRACKETS MAY BE MOUNTED ANYWHERE WITHIN ENCLOSED SPACE
- BRACKETS ARE DEMOUNTABLE

LATERAL CABLE





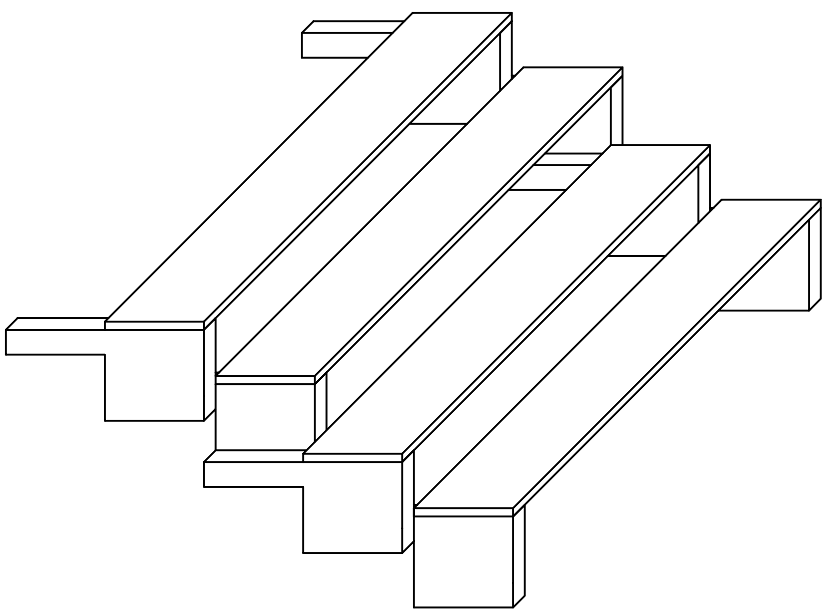
ADJUSTABLE TENSION DETAIL

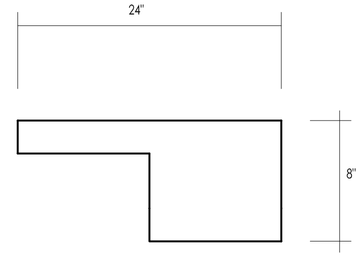


COLUMN AND CABLE ELEVATION

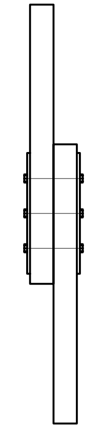
- HIGH TENSION STEEL CABLES PROVIDE LATERAL STABILITY
- OCCUR LATERALLY IN TOP TWO TRUSS ZONES

STAIR STRINGER

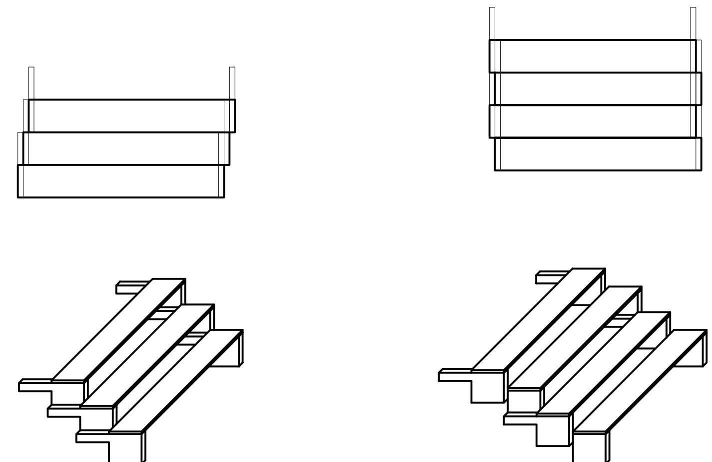




MODULE ELEVATION



CONNECTION DETAIL



POSSIBLE ARRANGEMENTS

- STRINGER MODULES MADE OF WOOD, CONNECTED WITH STEEL BOLTS AND PLATES

APPENDICE II. Cost Comparison Sheet

Cost comparison of a two story 2000sf enclosure – materials only; no windows, doors, mechanical systems, or finishes.

DIMENSIONAL LUMBER

8'x125' floor plan with 2x6 wall studs at 16" 0.c., double top plate, single bottom plate, prefab wood roof trusses, R30 roof insulation, R13 roof insulation, T+G ply for floors. Calculations rounded to nearest dollar.

Floor 1

floor – 100sf 8" thick slab on grade = 24.4 CY @ 65.10/CY = $1588
wall – 1330sf R13 @ .50/sf = $665
200 2x6-10' @ 7.45 each = $1490
26 2x8-10' (bot. plate) @ 10.50 each = $273
52 2x6-10' (top plate) @ 7.45 each = $387
1330sf gypsum @ .33/sf = $439
1330sf exterior wall sheathing @ 1.14/sf = $1516
1330sf TYVEK @ .05/sf = $67
1330sf exterior cladding @ 1.49/sf = $1982

Floor 2

floor – 94 2x8-8' joists @ 8.40 each = $790
31 4'x8' T+G ply @ 39.84 each = $1235
wall - 1330sf R13 @ .50/sf = $665
200 2x6-10' @ 7.45 each = $1490
26 2x8-10' (bot. plate) @ 10.50 each = $273
52 2x6-10' (top plate) @ 7.45 each = $387
1330sf gypsum @ .33/sf = $439
1330sf exterior wall sheathing @ 1.14/sf = $1516
1330sf TYVEK @ .05/sf = $67
1330sf exterior cladding @ 1.49/sf = $1982
roof – 31 4'x8'x½" ply @ 19.71 each = $611
1300sf R30 insulation @ 1.57/sf = $2041
1000sf coverage roof truss @ .50/sf = $500
1300sf roof tile @ .77/sf = $1001
1300sf gypsum @ .33/sf = $429
Labor - 2000sf @ 7.00/sf = $14,000
TOTAL = $36,163

PREFAB SYSTEM

Total necessary components

128 floor/ceiling panels @ 55.00 each = $7040
64 wall panels @ 24.00 each = $1536
15 18'8" columns @ 60.00 each = $900
15 13'8" columns @ 42.00 each = $630
15 9' trusses @ 33.90 each = $509
15 25' trusses @ 97.60 each = $1464
1152sf roof deck @ 1.60/sf = $1843
Labor - 2000sf @ 5.00/sf = $10,000
TOTAL = $23,922