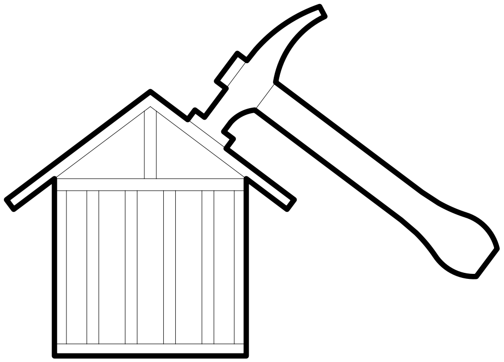
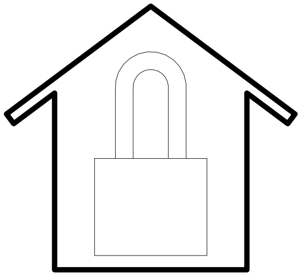



Adaptive Architectural Value Engineering

A Study of Influencing Factors

A Design Thesis Submitted to the Department of Architecture and Landscape Architecture of North Dakota State University. By Christopher Don Meyer, in partial fulfillment of the requirements for the degree of Master of Architecture.

Primary Thesis Advisor

Thesis Committee Chair

Table Of Contents

Thesis Proposal

Research

Design Solution

List of Figures And Tables

Abstract

A study to define value, and define it as a critical variable in domestic residential design and construction, by the use of evaluation of adaptive symbolic models using designer controlled endogenous and external exogenous variables to define a field of optimal solutions. An application of existing and derived methods, and tools, on designer defined preferential models of domestic architecture.

Theory

In 'The Structures of Scientific Revolution," Thomas Kuhn states, on the mechanics of General Systems Theory," *knowing one part of a system allows you to know something about another part." Before a paradigm shift occurs, knowledge must be pushed to its extent in theoretical and applied realms*.(Kuhn)

Professional architectural design is exponentially broad in scope of practice, with each subset of practice applying vastly different methods and defining doctrines. These methods and doctrines present a non-linear, cyclical design evolution of generalized and abstract ideas, with resulting solutions leading to a synthesizing of built environments. This evolutionary nature of design creates issues of continuity, resulting in wasteful time and budgetary overruns.

Narrative

Domestic residential design and construction is dependent on monetary and fiscal policies, and severe market fluctuations. The monetary and social effects of domestic construction have far reaching affects employment and the standards of daily life. Residential construction is largely practiced by independent builders and tradesmen, each completing a few homes a year in a city or region.

Residential construction in the United States, follows a history and social narrative not present in other post industrial or even developing nations. The concept of individual home ownership and to a large extent individual property as a right is a fundamental tenant of American value. This tenant is commonly referred to as the American Dream.

American life increasingly changed after the turn of the previous century. Progress in scientific knowledge and manufacturing advances, lead to the creation of consumer economics; with durable, low cost products available with ease.

The advancement of affordable housing has been a focus in economics and design since the Great Depression in the United States. The advancement of affordable housing was in the previous century, largely explored idea by some of our most iconic architects, engineers, and businessmen. From the Usonian Homes of Frank Lloyd Wright, to the advancement of social thinking through design sought by Le Corbusier in , *'Towards a New Architecture'* (1931).

These iconic figures of architectural thought and design shared commonalities of dogmatic approach which strongly align with practices value economics and design. Both Wright and Le Corbusier searched for, and professed for optimization in design and construction. Each with varying level of prefabrication and modularity in practiced design methods with the foresight to the potential for an applied simplification and optimization of design and construction methods.

The evaluation of existing design methods and tools, with a objective of optimal design, should result in adapted and new methods and tools which may advance current design thinking.

Current methods of architectural design allow for an accurate accounting of preferential or qualified thinking and for the judged aesthetics of form and scale. The establishment of numerically dynamic design tools in primary design synthesis is poorly established.

Domestic residential construction has been predominantly unchanged over the past 160 years, with most construction using stick framed, site built methods.

> *"The Engineers, inspired by the law of economy and governed by mathematical calculation, put us in accord with universal law. He achieves harmony."* (Le Corbusier, *1931, 1*)"

Innovations in new design and construction methodologies is needed to address social and economic factors of today and tomorrow. New philosophical understandings of value, and adaption and development of design methods may provide useful in the bridging of shortcomings of current practices. New methodologies have a need to express economy, and be socially progressive in application.

> *"Machinery contains in itself the factor of economy, which make for its selection. The house is a machine for living in. We must aim at the fixing of standards in order to face the problem of perfection.... Architecture operates in accordance with standards. Standards are a matter of logic, analysis and minute study; they are based on a problem which has bell well stated."* (Le Corbusier, Towards a New Architecture, *1931, 2*)

The house as a machine is well defined, supporting the daily functional progression of individual life. Understanding the function of the individual allows insight into the function of society as a whole. The adaptation and application of existing and new methods of domestic residential design and construction is logical and justified when judged when approaching optimal solutions to economic and social fact.

Project Typology
Residential Construction

Home
The place where one lives permanently, especially as a member of a family or household. (Oxford English Dictionary)

Project typology is a single family home not to exceed *2400* square feet and *112* USD a square foot in cost. House will have at least two bedrooms and one to two bathrooms with kitchen and family space. The architectural style of the residence is undefined. An application of adaptive value optimization will be applied in the design and construction methods use.

Typological Research

Image Source: National Trust for Historic Preservation Credit: Paul Burk

Pope-Leighey House   Case Study

Architect: Frank Lloyd Wright
Apprentice: Gordon Chadwick
Master Carpenter: Howard C Rickert
Location: Alexandria, VA

Owners:
1. Loren and Charlotte Pope 1940 to 1946
2. Robert and Marjorie Leighey 1946 to 1964
3. National Trust for Historic Preservation 1964-

Year of Design: 1939
Year of Construction: 1940
Floor Area: 1200 square feet
Cost:7000 USD
Cost Per square foot: 5.83USD
Median Income 1940: 956 USD
Median Home Cost 1940: 2938 USD
Target Price: 5500 USD
Typology: Residential
Style: Early Period Usonian Modern

"A home of moderate cost in not only America's major problem but the most difficult for her major architects." That house must be a pattern for more simplified and, at the same time, more gracious living: necessarily new, but suitable to loving conditions as they so be in this country we live in today." (Frank Lloyd Wright, Autobiography, 489)

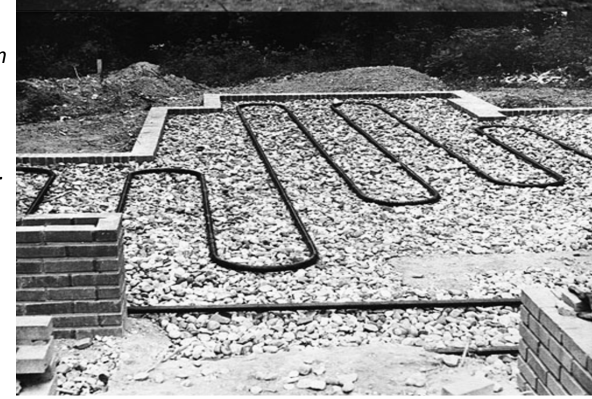
This house was designed by Frank Lloyd Wright in 1939 for Loren Pope. Construction began in summer of 1940 under direction of Gordon Chadwick, Taliesin apprentice; with Loren Pope acting as general contractor. Howard Rickert was hired as master carpenter. Construction was completed in winter 1941.

The design and construction methods use in the Pope House reflect Frank Lloyd Wright’s concern of providing cost effective housing to American's that were suffering from the economic and social effects of the Great Depression. The Pope-Leighey house is the third built example of Wright’s Usonian vision. Many of the concepts Wright used in his Usonian houses were earlier explored by him in his American System-Built Homes, prefabrication and module designs. These concepts were later applied in several key aspects of Usonian Design.

Key concepts of Usonian design can be listed as such: simplification of layout and floor plan, integration of mechanical and environmental systems, Introduction and use of prefabricated wall units and modular components, standardization of construction technique.

Pope house shortly after initial construction in 1941, showing office and carport.[1]

"The Living Room viewed from the North. Completion of the masonry walls. The Living Room is in the foreground on the left, Fireplace and Kitchen in the center, Dining Room on the right. Stairs leading up to the Entrance are complete."[2]



"Viewed from the Southwest, from the Entry toward the Living Room. The footings have been poured, and the row of bricks that borders the slab has been laid. Two-inch iron pipe coils for the radiant heat are placed on a bed of crushed rock, and will be embedded in the concrete slab. The Dining Room is on the left, the Living Room is in the center background, the exterior screened Terrace is on the right." [2]

1.National Trust for Historic Preservation
2.William Edmund Barrett Collection

The Pope-Leighey House is a residence with 1200 square feet of space. The house is constructed on a concrete slab. The house does not employ traditional framing, using quasi curtain wall construction and walling units. The house has a brick superstructure at its center. The outside scale is set by a one foot, one inch vertical course. The siding is cypress, horizontal batten and board construction. Horizontal brick joints are deeply raked to emphasize further the horizontal form. Exposed areas of brick are found on both the interior and exterior. The roof is one several planes and is a flat built up type of roof, topped with gravel.

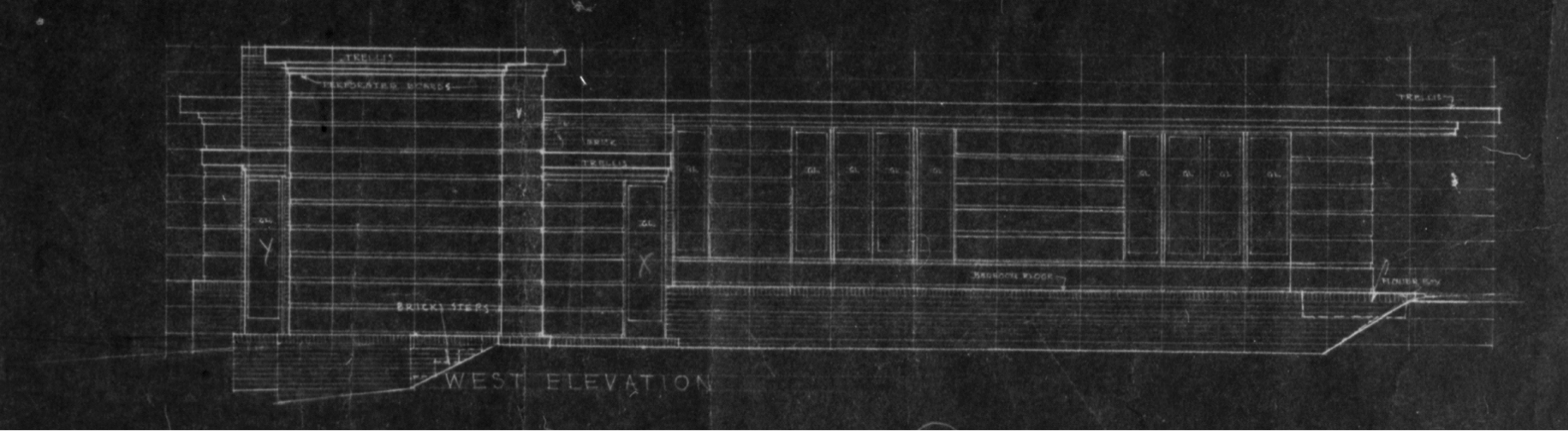
Usonian homes all share three primary interior spaces, centralized living area, adjoining kitchen and dining area, and bedrooms. Exterior finishes are carried to the interior. Wright simplified the interior to its minimal characteristic, providing only needed elements and finishes, no paint or plaster. This greatly would reduce maintenance of the interior, with only paste wax being used as a finish on surfaces. Furnishing were designed by Wright, and constructed out of plywood. This allowed a further simplification of the interior, allowing for better flow of space. This characteristic of totalistic design was also a common characteristic found in both international style architecture, and many forms of modernist architecture practiced from the 1950's onward.

The Entry and Office viewed from the West. Wide flange beam for supporting the carport roof are in place. The Office wall section is undergoing a test. "The experiment was conducted in Falls Church before attempting to convince the building inspectors in Baltimore, where the Joseph Euchtman House was also under construction, that the innovative sandwich wall without struts could bear the required load."[1]

The office viewed from the Southeast. "A wall section undergoing tests in 1940. The experiment was conducted in Falls Church before attempting to convince the building inspectors in Baltimore, where the Joseph Euchtman House was also under construction, that the innovative sandwich wall without struts could bear the required load." [1]

"Loren B. Pope Residence 1940. Viewed from the North during construction. The Living Room is on the left, Dining in the center and Bedroom wind on the right. The windows and doors appear to be installed, but the Perforated Light Screens in the Living Room have not.photograph." [1]

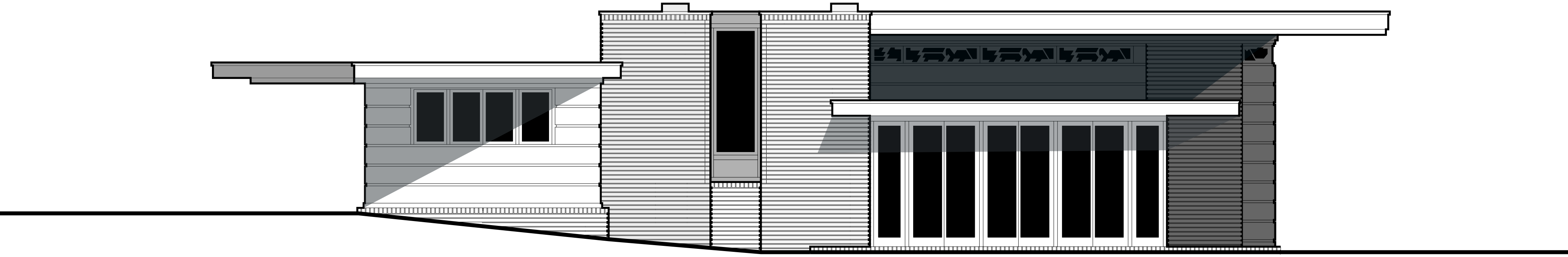
1. William Edmund Barrett Collection



The original construction drawing set for the Pope House only contained five sheets. On this elevation you can see Wright's vertical planning grid with 1'1" vertical and 4' horizontal lines. Image Source: Library of Congress Digital Collection

A Usonian home used grid planning. A horizontal two foot by four modules or grid controlled spacing and order in plan and a one foot, one inch in section and elevation. The modularity and construction methods match those of traditional Japanese architecture; with planning Tatami mats, which traditionally have a length to width ratio of 2:1. Plans as well as the slab concrete floors included this grid. This was done to allow builders to locate walls and place glazing units. Wrights grids were commonly based on material size, and were done in such a way to minimize waste. Builders were expected to use the grid as a story guide during construction instead of relying specifically on measurements; this idea would also apply to homeowners constructing their home themselves from a kit of prefabricated parts.

Disadvantages of this methodology were that many contractors and builders would not bid on a home using such unique construction documentation. As a system of arrangement, Wright's grid was overly simplified in a time that lacked strong national standardization of building products. Wright's idea of building based on product size is a useful, historically supported method of design and construction. Wright used five different grid planning systems in Usonian Design: Polliwog, Diagonal, Inline, Hexagonal, and Raised.



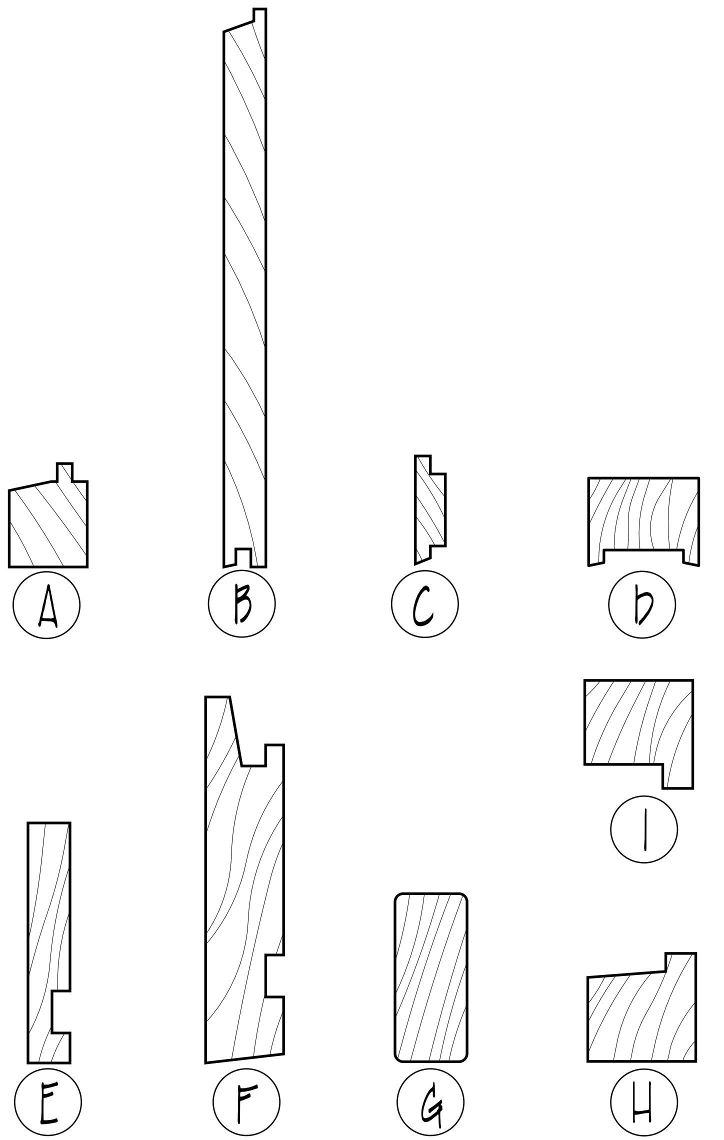
South Elevation

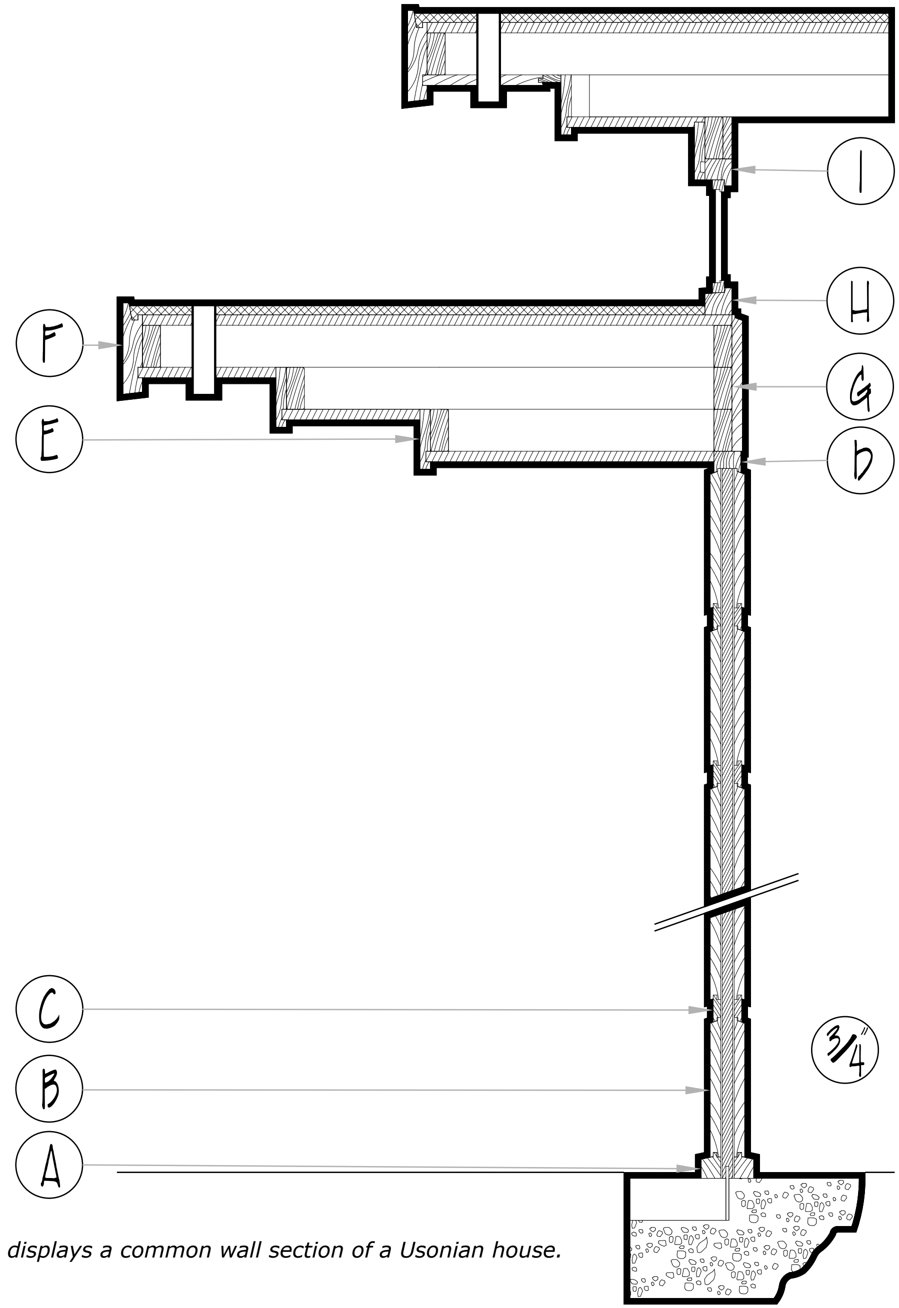
Usonian homes share common construction practices. A standard detail sheet was included with all Usonian house. This was done by the use of prefabricated windows and doors, and modular wall unit. Modular wall units used in the Pope-Leighey House are sandwich, board and batten type. They are constructed of four primary components: eleven inch Tidewater Cypress board, 7/8 inch plywood core, two inch batten strip, and tar or rosin paper used as a membrane. Once constructed, it would form both exterior and interior finish, and eliminate the need for plaster and paint. Wright preferred practice of construction was to construct the roof and brick superstructure first; at which point walling units and windows would be installed using the roof for support. Corners would be mitered. This is similar to current curtain wall construction, and was also seen in the international school of architecture. Construction documentation included with Usonian houses detailed instructions of production of walling units; and that they could be shop constructed, or constructed using slab grid as guide and then tilted up. This system had several key disadvantages. As constructed, walling units offered little insulation value. Theses walling units also had issues in integration of electrical wiring, with power being run along ceiling and through conduit to junction boxes and outlets. This is still an issue for sandwich panel construction.

"Loren B. Pope Residence Fall 1940. Viewed from the West, from the Master Bedroom. Workmen are putting the finishing touches on the concrete slab. The two foot by four foot grid has been scribed in the concrete. The pad was bordered with a row of bricks. The Living Room is on the left. The Dining Room is in the foreground. The Fireplace is in the center, the Kitchen is to its right. The screened Terrace is in the background. The Entrance is to the right." [1]

Close up of wall unit mock up showing build up. [2]

1. William Edmund Barrett Collection
2. Peter Christensen





Millwork Study

3"

This section displays a common wall section of a Usonian house.

The Pope-Leighey house, like other Usonian houses were designed to allow for future expansion with ease. Wright conveyed his idea through his principle of "Polliwog"(Tadpole).

> *"As you see from the plans, Usonian houses are shaped like polliwogs... with a shorter or longer tail. The body is living room and adjoining kitchen-and the whole Usonian concentration of conveniences. From there it starts out, with a tail: in the proper direction, say one-two bedrooms, three, four, five, six, bedrooms long; provision between each two rooms for a convenient bathroom."(Frank Lloyd Wright, the Natural House, pg 167)*

The Pope-Leighey House is classified as a L shape, "Polliwog" Usonian, and uses the two foot, by four foot gird in its planning organization.

The ease at which you can expand a design is greatly affected by economic pressures, changing demographics, and social dynamics. This has been greatly affected in the negative by land use policies, and floor to area ratios (FAR); leaving little options for flexibility in design. If the allowable floor space is excessively restricted, households can be at a disadvantage, leaving little options for affordable construction or expansion.

The Pope Leighey house is a style distinct to Frank Lloyd Wright. *"Every house is a missionary. I don't build a house without predicting the end of the present social order."(*Frank Lloyd Wright ,Oct1938) Usonian homes were both studies in functionality and sustainability; but, also in social and economic structures.

All Usonian homes share Wright's philosophies of Organic Architecture, using his "grammar" of design.
Each Usonian home was matched to client needs while using similar principles of organic architectural design. This similarity extended to principles of organization and a use of standardized components and construction methods.

> *"Each building has its own grammar, its distinct vocabulary of pattern and form. All parts of the building from the smallest detail to the overall form thus speak the same language. The grammar may be completely different for two buildings, although both are organically designed. "(Frank Lloyd Wright for the Architectural Record, 1908-1952. New York: McGraw-Hill,1975, page unavailable.)*

Usonian houses were semi successful in their footprint and cost. At 7000USD the Pope-Leighey house was still beyond the means of average Americans; with a median income of 956USD a year.[1] This made it a style available to only upper middle class families, and not "democratic" architecture envisioned by Wright. At 230 percent more expensive than the median home value of 2938USD in 1940, it becomes difficult to label these homes (Usonian Houses) as low cost. It is possible however to use their value of efficiency and planning in modern design practice. Keys to this are a simplification and modularity of construction and the use of durable, natural materials.

“It is not only necessary to get rid of all unnecessary complications in construction, necessary to use work in the mill to good advantage, necessary to eliminate so as far possible, field labor which is always expensive: it is necessary to consolidate and simplify the three appurtenance systems – heating, lighting and sanitation. At least this must be our economy if we are to achieve the sense of spaciousness and vista we desire in order to liberate the people living in the house.”(Frank Lloyd Wright, Autobiography, pg 490)

The Pope-Leighey House integrates environmental and mechanical systems into a service corridor. This included locating mechanical systems at the core of the house close by the kitchen and bathroom. This greatly reduced the distances that systems needed to be run through the house. Hydronic floor heating is used in the Pope-Leighey house, which made it possible to get rid of the basement and radiators. This simplified construction needed to incorporate them, freeing up floor space. This allowed for a more condensed floor plan that was more efficient. Again, this idea matches closely values in design being practiced in international style being practiced in Europe.

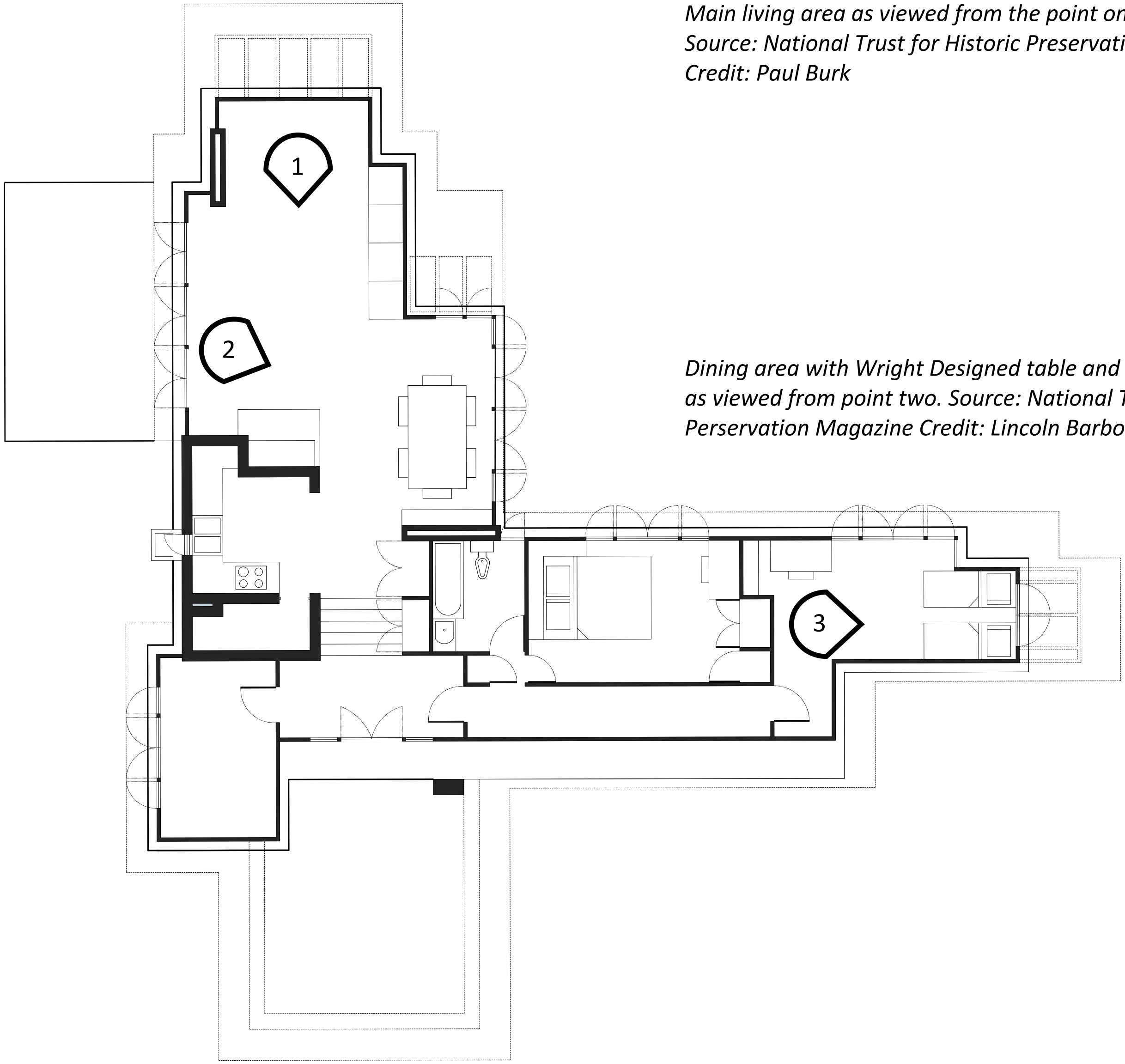
Simplification and integration of systems into the built environment enable design to match economic and environmental standards of current practice.

"These are an integral part of the building: they are not added on, stuck in or unduly exposed. Sculpture and painting have to become elements of the total design." (Frank Lloyd Wright for the Architectural Record, 1908-1952. (New York: McGraw-Hill,1975), page unavailable.)

This photograph shows the children's bedroom at the end of the structure. All furnishing were designed by Wright as an integral part of the overall built environment. Photo Credit: National Trust Preservation Magazine: Lincoln Barbour, photographer

Looking at northeast corner of house outside the children's room. Photo Credit: National Trust Preservation Magazine: Lincoln Barbour, photographer

Looking at northeast corner of house outside the children's room. Photo Credit: National Trust for Historic Preservation: Paul Burk, photographer



Main living area as viewed from the point one.
Source: National Trust for Historic Preservation
Credit: Paul Burk

Dining area with Wright Designed table and chairs, as viewed from point two. Source: National Trust Perservation Magazine Credit: Lincoln Barbou

Floor Plan

Image Source: Rural Studio

Dave's House 20KV8 The Rural Studio Case Study

Location: Newbern, Hale County
Year Built: 2009
Size: 616 square feet with 112 square foot porch, total 728
Style: Shotgun with footing elevated platform foundation
Median House Value: 2009-209700USD[4]
Median Square Foot: 2256 [4]
Median Income Alabama: 2009-40489UD=SD[4]
Project Cost: 20000USD
Material Cost: 12500USD
Construction Cost: 7500USD
Material Cost Per Square Foot: 17.17USD
Construction Cost Per Square Foot: 10.30USD
Overall Cost Per Square Foot: 27.47USD
Appraised value: 45000USD

The Rural Studio is a design, build architectural program of Auburn University, located in Newbern, Alabama. The studio practices outreach architecture, serving underdeveloped, low income, rural areas. The studio's founder, Samuel Mockbee was convinced that architecture has a moral responsibility, needing the practice of strong ethical imperatives in order to be a meaningful professional field. The studio is focused on incremental change *"practicing sustainability with a same s."(*Mockbee) The design philosophy practiced at the studio focus on climate sensitive, energy conserving, low tech construction, with an overall ease of maintenance and economy. Materials and methods are judged foremost by economic factors. The studio practices collaborative, integrated design working closely with affected communities and clients; educating "citizen architects," through social activism.[1] The studio focuses on vernacular materials and styles.

1. Term developed by Samuel Mockbee

20K Houses

Since 2005, the rural studio has developed its 20K experimental housing prototypes of affordable housing. The prototypes all have the principal characteristics of efficiency, durability, that form a well built home.[2] This idea was explored since 1994.[2] The initial goal of the project was to design a housing model rated by market function; for individuals on fixed low income or unable to qualify for credit. Homes would cost 20000USD, with 12000USD for materials and 8000USD for labor and profit. It was found that a 20000USD mortgage was the maximum amount an individual on social security could afford.[3, pg. 202] At 785USD a month it would equate to a maximum mortgage payment of 108USD.[3, pg. 202] This would be roughly thirteen percent. This is lower than the twenty eight percent of income to thirty one percent commonly used by lenders.

It was found that material, labour, and material costs could accurately be accounted for and controlled. The greatest limitations were found to be in vast differences in building regulation from one jurisdiction to another. This seems to be the most common factor in trying to develop a more universal affordable housing type; with materials and practices greatly varying.

20K Product Line

The 20K Product Line began development in 2009, and used earlier 20K house prototypes as a basis. Regions Bank approached the studio wanting to progress the 20K design from an experimental platform to a viable microeconomic product. Difficulties in financing home construction are a recurrent issue for markets. Traditional financial products limit greatly types of construction, and quality attributes needed to obtain them.

By reducing components to purely needed ones, cost can be greatly controlled; this allows for a faster construction time with improved ease. This is displayed in the time needed to construct most 20K homes; in a period of three to four weeks.[3, pg.202]

Future Challenges

The Rural Studio through their work has defined major challenges to the future development of the 20K Product Line. The first issue identified the studio was of how you accurately adjust for price inflation. It was found that completed homes were assessed 100 to 150 percent higher at 40000USD to 50000USD by insurance companies. This can be attributed to statistical bias in price per square foot being used in an over generalized cost being provided by standards organization, such as Marshall and Swift. This also reflects how slow markets adjust to changes in preferences. This lead to the further question of why would a contractor limit themselves to the fixed profit margin in the construction of a 20K home.[3, pg 223] This becomes a fundamental question in today's society; were housing is a speculative commodity.

2. Rural Studio.org

3. Rural Studio at Twenty, Designing and Building Hale County, Alabama.

The microeconomic function of local market interactions appears to be the best method to decide cost and price. Macroeconomic and housing policies respond to slowly to accurately account for quick contractions and expansion seen in local markets. Another issue identified was lack of, and adaptability of current financial products.[3, pg.223] The cost to write a mortgage was found to be the same for either a 20000USD loan, or 120000USD loan.[3] The question becomes what incentive is offered to financial institutions to write and provide micro financial products. The development of new financial products may answer question. Guidance through governmental fiscal and monetary strongly dictate the costs and types of financial products. This becomes an ethical question not easily answered.

Another important question raised by the studio is how as designers, contractors, or developers, we maintain quality of our products as they become more proliferated in our society. It is important to use a strong standard of materiality and construction to maintain quality in designed environments.

The owner of this home Dave, sitting on his porch.[1]

Dave's house under construction in August of 2013. [1]

2. Rural Studio.org

3. Rural Studio at Twenty, Designing and Building Hale County, Alabama.

The final issue identified is land use polices.[3] This issue is common place scholastic progress of architecture since 1900, shifting with demographic changes for rural to urban and from urban to rural. The most historically influential architects indentified the importance site plays in the success of the built environment. The greatest impact on future design will be from a overgeneralization of building standards. The adaptation by case should be considered in residential construction, and address vernacular techniques and materials.

The structure uses factory finishes as much as possible to regulate cost. It was found that streaming of construction processes allowed for a quicker construction created a saving on labor. This allowed an additional 500USD to be allocated on material. [2] It was also found footing and platform construction accounted for the greatest amount of expense.[2] The use of simple materials selected by economy and durability are well demonstrated in this case.

Models produced by the Rural Studio. Showing at top, front of the home with porch. At center, close up of front porch showing construction details. At bottom, showing the rear of the home. Images Source :Museum of Modern Art.

2. Rural Studio.org

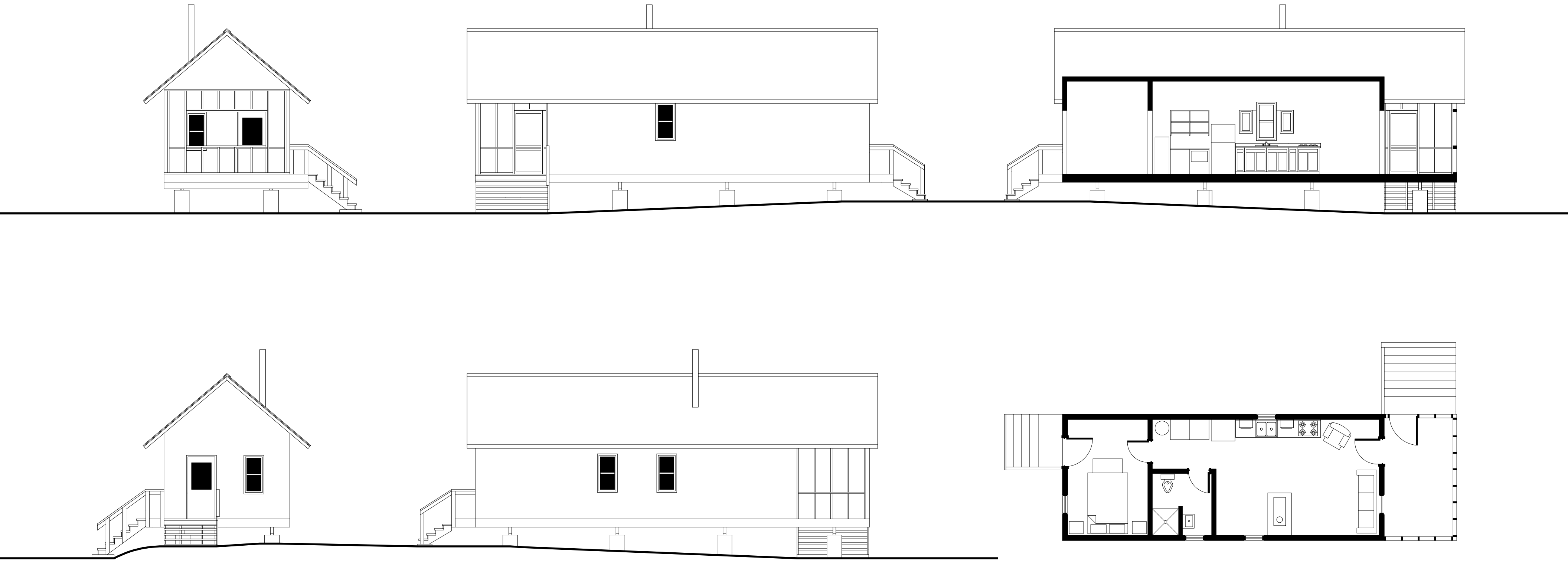
3. Rural Studio at Twenty, Designing and Building Hale County, Alabama.

Characteristics of 20K Design

All 20k Product Line homes have shared construction characteristics. Unlike earlier attempts to create affordable housing with simplified , cost effective wall construction with poor thermal qualities, all 20K homes have a minimum six inch wall cavities, allowing for at least a R21.[3] Higher R values align themselves with a energy efficiency of current leading standards. Higher R value should allow for savings in cost as energy prices fluctuate. At an R21 this meets or exceeds most code restriction for thermal performance currently. Ceiling height in all 20K homes are nine foot plus. This is done for two reasons. The higher ceiling creates a sense of space, making the smaller footprint feel larger. Higher ceilings also allow for the passive cooling of the structure in warmer, damper climates. Historically, vernacular design of warmer climates has used higher ceilings for cooling. Active mechanical systems greatly reduced this practice.

The interior of Dave's house showing the simple finishes and furnishings. Image Source: Museum of Modern Art.

The interior of Dave's house showing the kitchen and rear door. [2]



Project Elements

Major Project Elements

Description of Space

The project is a mid size residential structure, of one to two stories. The structure is not to exceed 2400 square feet. The residence is a single family home. The layout consists of at least two bedrooms, with a minimum square footage of seventy and a maximum of 250 square feet. Bathrooms at minimum will be one full bath, located adjacent to bedrooms, and half bath located near the family space. General use spaces are a family space of 550 square feet, and a kitchen of 550 square feet. The entry space will be adjacent to the kitchen or family space. A mechanical room is adjacent to the kitchen and half bath.

Primary Spaces

- Master Bedroom
- Bedroom Two
- Full Bath
- Half Bath
- Kitchen
- Family Space
- Mechanical
- Entry

SPACE MATRIX

	Master Bedroom	Bedroom Two	Bathroom One	Bathroom Two	Mechanical	Kitchen	Family Space	Entry
Master Bedroom		**▢**	**▢**	□	■	□	□	■
Bedroom Two	**▢**		**▢**	□	■	□	□	■
Bathroom One	**▢**	**▢**		■	■	□	□	■
Bathroom Two	□	□	□		**▢**	**▢**	**▢**	■
Mechanical	■	■	■	**▢**		**▢**	**▢**	**▢**
Kitchen	□	□	□	**▢**	**▢**		□	■
Family Space	□	□	□	**▢**	**▢**	□		■
Entry	■	■	■	■	**▢**	**▢**	■	

▢ Conneted □ Nearby ■ Not Connected

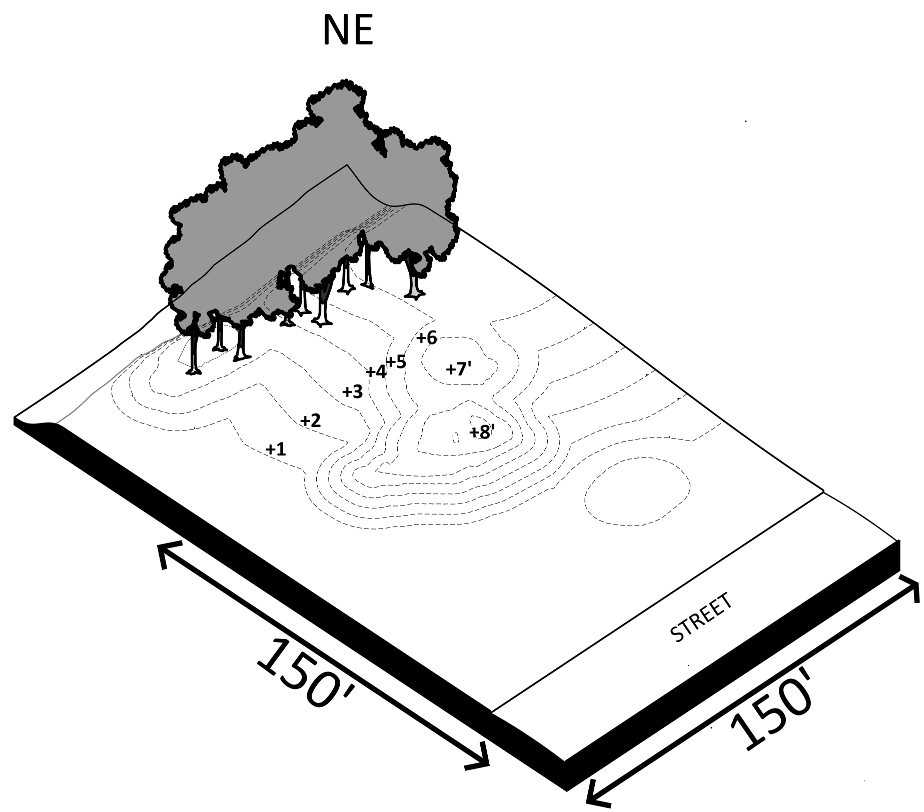
SPACE ALLOCATION TABLE

	Min		Max	
Master Bedroom	100	*11.91%*	250	*10.87%*
Bedroom Two	100	*11.91%*	250	*10.87%*
Bathroom One	70	*8.34%*	150	*6.52%*
Bathroom Two	*	*8.34%*	100	*8.34%*
Mechanical	70	*8.34%*	150	*6.52%*
Kitchen	70	*8.34%*	550	*23.91%*
Family Space	250	*29.78%*	550	*23.91%*
Entry	70	*8.34%*	100	*8.34%*
Circulation 15%	109.5	*13.04%*	300	*13.04%*

**Minimum Sqaure Footage Set By IBC R.304.2*
**Garage is not accounted for in table*

User Client Description

The clients are a married couple in mid thirties without a child. They have some level of post secondary education in a professional field. Their income together is *59039* USD a year. This is the median income for the Midwest and is sourced from the United States Census Bureau. They have *14759*USD to spend yearly on construction which is twenty eight percent of their income. This would allow for a monthly mortgage payment of *1229*USD. The house will not exceed *2400* square feet. They wish to have two bedrooms and at least two bathrooms. The design should allow for future expansion to at least three bedrooms if necessary. The design should not exceed *112*USD a square foot. They also expressed a need to store two vehicles. The home will have air conditioning and forced hot air heating. This is representational of homes constructed in the upper Midwest.



Site

Site Description

Fargo North Dakota

The site is symbolic model of a *22000* square foot lot. Modeling and project goals need to be generalized site to create unbiased results. Performace modeling will use geographic data related to the location.

Project Emphasis

This study is the application of optimal design methods applied on domestic residential construction. The emphasis is on the evaluation of existing methods and tools for optimization and the development new adapted methods. Methods and tools will be used in the modeling of a single family home. The basis points which must be meet are, a value of economy in design, construction, and operation, the ease of construction, the sustainable nature of construction, and the overall security provided in the built environment.

Economy

Systems selected for construction should use a practical commons sense when selecting affordable materials that would be common to the average individual. Economy should be maximized through careful application of budgetary concerns through understanding of limitations and client concerns. The delivered building should offer the greatest return on investment possible to client. Projects should be done in a manner that minimizes the affects of broad macroeconomic market affects.

Buildable

Selected systems should maximize the efficiency of building construction through the minimizing of components needed in construction. Delivered building should have the lowest possible occurrence of needed maintenance, repairs, and component replacements over the useful life of the building. Construction should have some form of modularity through materials and standards use. Delivered building should account for the need for future expansion and retrofits; these should be performable with the greatest amount of ease with the less amount of cost. Erection of building should be able to be performed by any local contractor. Delivered buildings should meet or exceed residential building codes. These functions can be performed through the evaluation of new and existing residential construction methods.

Sustainable

Sustainability defined: the limiting of waste in construction and the minimizing of energy consumption in construction and operation of the built environmental. Materials and systems selection should be based off durability, with the characteristics of longest life and lowest maintenance. Product sourcing should use local suppliers as much as possible out of a sense of greatest economy. Savings in construction is done through the minimal application of durable materials.

Secure

Residence need to display the highest level of protection from environmental and social hazards possible. An understanding of the reasonable care should be applied and practiced. The application of the durable materials and systems should minimize rate of hazards

Goals

Academic Goals

Information derived from this study will hopefully provide direction which enables some advance in scholastic thinking. This study is part of program requirements for the completion of Masters of Architecture at North Dakota State University.

Professional

The application of methods and tools created by this study will provide insight to critical architectural design. Application of methods will provide savings in materials and time. This further extends to application to residential construction in the Metro and surrounding region.

Personal

This study is not only an evaluation of others perceived ideas of design and methods, but also an internal evaluation of personal ideas and biases. I believe quality in construction is the foremost goal a designer should reflect in their work. This period of study allows a critical evaluation and forming of these ideas. The mark of quality is an extension of family tradition, with each generation striving to reach the apex of their craft.

Plan for Proceeding

Research Direction

Theoretical Premise

Research moving forward will try to correlate design methodologies with optimal forms of analysis. This research will include historical methods and approaches to optimal design. Research will need to also be focused on simplified design tools and applications. There is a need to understand value in architectural design, and its impact on design methods, material selection, and cost. Research will need to define value, how it is perceived, and applied.

Project Typology

Research will focus on both historical and present examples of simplified, optimal designs. This process will allow the evaluation of successful application of optimal methods. A need will exist to analyze not only methods of construction, but also philosophical doctrines of design. This will include numerical and graphic analysis. Research results should provide methods of construction.

Contextual Research

New methods of design methods of optimization will require the creation of benchmark standards. This will be representative of averages of demographic and topological data from the US and upper Midwest. This data will be used in analytic models to generate client and user, site, background demographics, construction materials and methods, and space types and allocations.

Documentation Method

Documentation will be completed in a digital format with time, date, and file designation. Deliverables will also follow this format and be utilized in best academic traditions.

Methodolgy

Professional architectural design is exponentially broad on scope of practice, with each subset of practice applying vastly different methods and defining doctrines. These methods and doctrines present a non-linear, cyclical design evolution of generalized and abstract ideas, with resulting solutions leading to a synthesizing of built environments. Research will continually to conduction throughout the thesis preliminary research, schematic design, model and application development. This information will be used in the further application and evaluation of methods of construction and optimization. The adoption of a transformative method of research and design will be adopted.

Schedule

The schedule will be follow direction provided by primary thesis advisor and thesis review board.

Thesis Proposal Due ***December 14th***
Thesis Program Due ***December 14th***
Thesis Final Edited Program ***March 9th***
Mid-Term Thesis Review ***March 5th through 9th***
Digital Copy of Thesis Exhibit ***April 20th***
All Physical Exhibits Due ***April 23rd***
Exhibit ***April 23rd through 25***
Thesis Reviews ***April 30th through May 3rd***
Digital Copy of Thesis Book Due ***May 7th***
Thesis Book Due ***May 11th***

**These dates are provided by thesis manual*

Research

Research
Optimal Frontier

To develop an architectural design with an optimal solution, an understanding of the mechanics of design process becomes important. In *'Design by Optimization in Architecture, Building, and Construction'*, architectural design is defined as *a goal-directed activity in which decisions are made about the physical for of the building and their components in order to ensure their fitness for the intended purposes. Further, that design itself is comprised of three primary identifiable phases, problem analysis, design synthesis, and design evolution, which are performed in a cyclical process by conscious or unconscious sorting of design goals.* (Greo, Radford, 1988)

This process of design moves from generalizations about design defined in a broad terms, methods, and doctrines, and results in optimal design solutions. These solutions may or may not be the optimal answer to the design problems. The cyclical form of design becomes well suited for the introduction of value mapping and continual improvement practices. Architectural design is not often thought of in this manner, lacking proper evaluation of design changes and post occupancy analysis. Gero and Radford, 1988, refer to the a bias present in design practice in which a designer over rely on personal judgment in the decisions affecting the tradeoffs between design solutions without proper numerical or practical reasoning to meet client or social expectations at the cost of performance in the final product.

Does form follow function, or function follow form? In a optimal method of design, the cyclical evolution of the solutions allows for both statements to be true. This allows a balancing of aesthetics to performance sought in an optimal solution to a design problem.

"Each building has its own grammar, its distinct vocabulary of pattern and form. All parts of the building from the smallest detail to the overall form thus speak the same language. The grammar may be completely different for two buildings..." (Wright, 1952)

Constraints

The constraints imposed by site conditions, regulations, and client directives, limit the range of possible design variations. "*Architects and other designers tend to work within a language (a style) of design that is peculiar to a individual, a school, or a age."* (Gero and Radford, 1988) Greo and Radford (1988) and Wright (1952) define design or design synthesis as limited to, and practiced with a language and style which may not be related to other forms

Gero and Radford (1988) refer to the limitations of design evolution, "*design solutions in any particular situation are not unlimited and cannot be treated as if they were."* This statement defines the limiting factor, with the applicability of one case presenting an optimal solution which is foreign or inappropriate in another. Each design will present its own defined optimal solution which may or may not be generally applicable to design thinking

Methods which may prove applicable to general design thinking must be adaptable, translatable, to different forms of design language or grammar. By seeking commonalties in design and applying and evaluating different design methods, a synthesizing of a optimal solution may occur.

Design Synthesis

Design synthesis is the making of decisions within a design language and under project specific constraints, using models based on information about whether the decision that will further the advancement of the body of design goals. (Gero and Radford, 1988) Design has a need, in the seeking of optimal solutions, to correlate concerns and constraints in the appraisal of a design solutions. The appraisal of design solutions is completed in two manners, non-preference, and preference methods.

"Before a design can begin a designer needs a model of the problem, in the mind, written down on paper, expressed as diagrams, expressed as symbols, or some combination of theses." (Gero and Radford 1988) In the development of an optimal method numerical symbolic models present the form for optimization, describing a design or project in dynamic terms. This form of modeling has three distinct categories: simulation, generation, and optimization. (Greo and Radford, 1988)

Simulation

Model simulation predicts the performance consequences by manipulating a numerical model. All evaluation and decisions are external to the model.(Gero and Radford, 1988) This form will develop a field of options based on none adaptive function. In simulation modeling the model parameters do not change internally and are none adaptive. Simulation has little value in optimization, except in the testing and defining of benchmarks for evaluation to be used in a manipulative generation models.

Generative Modeling

Generative modeling explores the consequences of a set of decision rules, with some form internal evaluation and changing of model parameters. (Gero and Radford, 1988) This form of modeling when combined with simulated outcomes will produce a optimal method for the evaluation of project specific parameters.

"Optimization is defined as the ranking of performance solutions or partial solutions when measured against the defined objective or optimal outcome." "Optimization models effectively searching the whole field of feasible solutions and identifies those suited to the designers stated goals. This is an attempt to answer the designer's fundamental question of what is the best solution."(Gero and Radford, 1988)

Methods of Selection

Non Preference Method

Non-preference methods of evaluate a field of possible solutions and selects an optimal point, with no evaluation or reference to designer preferences.(Gero and Radford, 1988) This method will return an optimal solution, but at the cost of other criteria. This allows for easy evaluation of purely numerical forms of optimization but does not take into account aesthetic qualities of a design which are important evaluation references in critical architectural design. The use of preferential methods of evaluation are needed to properly evaluate the all the design criteria presented by the nature of architectural design.

Perference Method

Preference methods of design evaluation take into account some prior assumptions of relative importance (in the design) and use this information in the generation of a field of solutions. (Gero and Radford, 1988)

Limitation to Optimality

A main limitation to generation of a optimal solution is the correct defining and correlation of variables and objectives. The correct definition of variables is important, and needed in the formation of a prescriptive informative model.

Value Defined

Value is a self defined ranking of either, or both, quantitative or qualitative variables. Value is the perceived or actual value of an object, method, or process. The self defining and ever changing nature of value is its most limiting factor to the useful introduction in design processes. This self defining nature of value, limits its use in over general application to design problems. Value is the optimal return of the sum of all internal and external variables and constraints. It becomes important to isolate value from quality in all methods of design optimization.

Quality Defined

Quality can be defined as the state of performance or durability of a process, method, or material. Quality in the built environment relates to product finish, methods of construction, and effectiveness of the environmental success of a built environment.

Economic Variables

Economic factors are the quantitative results of market function. Market functions are exogenous variables outside the control of a designer. These variables are further defined as the broad social and financial trends of a context in which a designer practices.

Value Variables

Value variables are either or both, qualitative or quantitative user defined and ranked factors of importance. These variables in architectural design are commonly attributed in terms of quality of material, perceived value of an object, or the cost to return ratio of a project.

Endogenous Variables

Endogenous Variables, are model variables are ones that a designer is in control of. These relate to some forms of budgetary limits and material selection.

Exogenous Variables

Exogenous variables, are model variables which are outside of the control of a designer. These variables can be accounted for in modeling, and relate to economic trends and supply prices.

Discrete Variables

Discrete variables are finite in their discretion and limited to a specific number of answers or values.

Discontinuous Variables

Discontinuous variables range in value based on threshold of imposed by each specific case.

Methods of Optimization

Optimization uses selected variables in the selection and evaluation of optimal solutions to design problems. These selected variables take two forms, user controlled endogenous and externally fixed exogenous variables. Each variable type may or may not be dependent on a model as whole, or a singular optimal point. These variables should be accounted for, and defined for proper evaluation of optimal solutions. Exogenous and exogenous variables are used to define test model parameters.

Optimization can be defined as the optimal value received by and optimal solution. This solution can be either numerical or a qualified benchmark of performance that is either an internally controlled user defined or externally defined objective, which must be accounted for in model parameters.

Architectural Variables

Variables relating to architectural design practice are usually defined as a specific value related to material, size, or as a limit or threshold imposed by building code regulation. These two forms of design variables are defined as either discrete or discontinuous. (Gero and Radford 1988) These variables play little role in optimization processes since they are usually external exogenous and fixed.

Benefit is received from these variables is in allowing the definition of constraints and bounds the field of possible singular solutions. This would result in the improvement of overall model efficiency.

The identification of requirements, and an understanding of constraints allow for the accurate evaluation of new and existing technologies in economic terms and code compliance. The evaluation of economic factors, incentives and funding, code enforcement, standards of construction, climate, geology, and vernacular appropriateness of style , in the development of a field of optimal solutions to architectural design problems.

Optimization Simply Defined

Optimization can now be redefined into simple, commonly understood terms, as the maximization and or minimization of a defined problem or wanted condition, to return a optimal solution. To create an optimal solution to a design or in construction, several methods can be employed. Each method will vary to meet defined outcomes. Historically, optimal solutions to architectural problems was reached and understood as result of a simplification of form, construction methods, and materials.

> *"It is not only necessary to get rid of all unnecessary complications in construction, necessary to use work in the mill to good advantage, necessary to eliminate so as far possible, field labor which is always expensive: it is necessary to consolidate and simplify the three appurtenance systems – heating, lighting and sanitation. At least this must be our economy if we are to achieve the sense of spaciousness and vista we desire in order to liberate the people living in the house.* (Wright, 1952)

The consolidation of design components is one method which allows for the simplification of the built environment. This is easily implemented and applied by the adaptation of and use of existing principles and methods. The resulting solutions can be used in simulation and generation of the design solutions.

Feasibility Considerations:

How does the built environment meet occupancy standards?

It is critical to evaluate materials, systems, and practices to understand the performance criteria presented by each. Performance is broadly defined and dependant on both technological advancement, and the context in which the technologies are applied. Social factor will affect the performance outcomes of the built environment. These social factors are exogenous and outside of designer control.

Having clear performance objectives will drastically affect the success of optimal design solutions. It is necessary to be practical in the selection of design performance criteria.

Contextual Reasoning

Historical and Current

Traditional methods of residential construction have been predominantly unchanged for the past 160 years, with mostly homes constructed as wood framed, stick, and site built houses.

More recent trends in housing economics have been greatly distorted by volatile economic and environmental factors. Growth rates in domestic residential construction reflect this, with flat levels of growth since 1983, when the growth rate was 7.83 percent. In 2017, the growth rate in construction was within a range of three percent. [1] Historically, previous to 1950, the rates of sector growth ranged annually from thirty to fifty percent.

In his book, *'The Rise and Fall of American Growth; The U.S. Standard of Living Since the Civil War*,' Robert Gordon states, *"many innovations that lead to both an increase of production and efficiency can only occur once."* Coupled with the views of economist, Herman Daly, that the economy is dependent on the Laws of Thermodynamics, one can frame the level of housing output and construction as a important factor in the economic health of domestic markets.

Current economic and growth trends show an economy in a declined rate of product and growth, which is incapable of higher rate of growth without drastic innovation with efficient capitalization of finite mineral and energy resources.

These trends point to an economy in a state of decline. These limiting factors significantly constrain any economic and social growth potential that could match prior historical production of industrial growth . A redefining of how our housing economics are viewed is needed.

1. Bureau of Economic Analysis

Redefining of the Domestic Economy

Kenneth Boulding, in his book, 'The Economy of the Spaceship Earth,' wrote of two types of prevailing economies, the "spaceman, and cowboy economies."Boulding explains that, a *"Cowboy Economy*," is one that is gauged by a quantity of production and the level of consumption. This definition matches the historical industrial growth, and energy and material consumption seen in domestic markets before 1972.

The second economic classification, according to Boulding, is a *"Spaceman Economy,"* which is concerned with stock maintenance of existing resources and the optimization of processes and material use. This is achieved by the use of innovative technologies. This definition of economic function matches the dogmatic beliefs present in present methods of sustainable design and construction.

Housing as an Economic Tool

Domestic residential construction is dependent on the availability of affordable financing. Financing is available through private or government sector lenders, each having requirements which must be followed in design and construction. Both available funding and incentive are necessary to move conceptual design to active construction. Budgetary limits will define the scope of design and the limitations to performance. The success of new residential construction is based on the effectiveness of funding resources and incentives to build.

In 2016, 466.9 billion USD was spent on residential construction. This figure presents significant opportunity for improvements in residential construction methods.[1] New technologies, building products, and construction methodologies will greatly improve the standards of living. Investment in residential construction creates new jobs and impacts the health of local and regional economies. The Improvement of building methods and practices allows for the construction of homes with a better overall durability. The construction, maintenance, and operating costs that are part of home ownership contribute sustainably to the economic burden of the household. Better quality construction will decrease future maintenance costs and limit the need for repairs or replacement.

1. Bureau of Economic Analysis

Housing Life

The expected life span of domestic residential construction does not match that of its makeup of individual components. This statement is proved by the current average life span of housing as thirty five years, domestically. This is a result of exogenous economic variables. This economic condition correlates with terms of amortization, with periods ranging from fifteen to thirty years as an average.

The planned obsolescence of housing and stock maintenance is also limiting, though occurring at a lessened rate. The analysis and use of value engineering allows for the correlation and evaluation of these trends.

Ethical questions arise from the concept of using residential construction as solely an economic tool. Value engineering and optimal practices dictates that both the use and quality of materials and the performance must have a return on investment over the period of use or life expectancy of built environment. Domestic residential design and construction is found to rarely follow value methodologies.

A Need for New Methods

Professionals who are employed in the design and construction of new homes, need tools and methods that provide guidance in the selection of materials, technologies, and construction systems in a adequate and practical way. The integration of building professions in residential design and construction is necessary for the continual improvement of performance. The design process should include architects and engineers, building contractors, allied trades, product manufacturers, and critically the client.

It must be taken into account that due to the broadening scope of domestic residential design and construction, that knowledge bases, and methods will vary greatly based on jurisdiction and from professional to professional. New methods and practices need to be defined in clear and relevant terms for mass audiences.

The application of cost analysis and integrated design tools allow far more affective impact on design improvement. Algorithmic cost and design functions applied in methods of linear programming optimization allows the linking of improvement theories to practice.

Value Engineering

Value engineering is a systematically structural way of approaching design by developing an optimal solution to design projects, products, and processes. Value engineering is a commonly practiced method of critical design and analysis in construction and manufacturing. It provides both methods and philosophical doctrines for the evaluation and development of building performance to economic solutions. Value model analysis, analyses the performance variables of the designed environment to derive the lowest cost per opportunity optimal solution. This would be defined in common terms, "the best bang for your buck." In this type of modeling terms or factors can be defined as either quantified or qualified variables of both endogenous and exogenous nature and measure. This type of analysis is mechanically scientific and principally holistic. It has the possibility for further application in architectural design.

Cost Benefit Analysis

Professionals practicing in the design and construction fields should perform cost benefit analysis throughout the totality of a project. The complexity of evaluative studies, range from simple to complex. Analysis and evaluation should be crafted relative to each case, changing in measure and scope varied with the desired end use goals. The forms of accepted analysis in contraction are first cost, also known as simple cost, return on investment, and life cycle analysis, linear programming optimality analysis.

The recommendation for materials, technologies, and building techniques are most times selected by having the least first cost or upfront cost. This method does not account for the long term performance outcomes or the lifetime quality of the product or methods.

The early identification of budget goals and constraints allow for the shifting of budgetary allocations to increase the performance of the final product. Different interpretations of the projects emphasized goals have the tendency to shift performance and economic criteria. . A developed understanding of weighted advantages or disadvantages of a design solution can change the feasibility budget allocation changes. Using a practical determination when weighting performance criteria of different design solutions allow for the adequate optimal balancing in construction, while addressing also the economic limitations.

Mathmatical Methods

Mathematical programming uses symbolic analytical methods to iterate and resolve an optimal solution form a field of possible solutions. *"The analytic method is concerned with the moving of existing solutions to improved ones, until no better solution can be reached."* (Gero and Radford, 1988) This process of iteration is the basis for linear programming techniques of optimization. This method involves the defining of decision variables, constraints, and a function which is be optimized, known as an objective function. *"This method allows the return of an optimal solution in a fixed number of iterative steps."* (Gero and Radford, 1988)

Linear Progamming

Linear programming offers to provide insight to cost patterns and trends which affect the overall success of the built environment. The adaptation of linear methods allow the use of most numerical and qualified variables represented in critical architectural design.

The main limitation to using linear methods is the need to accurately define appropriate system variables and parameters in order not to result in a biased solution. Application of operational methods on current forms of preferential models may correlate expressed economic concerns in advance to the design process.

Simplex Methods

Simplex optimization provides the optimal method for solving linear equations presented by critical architectural design. The Simplex method of solving linear programming problems returns a optimal solution in to a user defined objective function by iteration of designer selected decision variables. This performed by means of Gaussian reduction and back substitution to return a final optimized tableau in echelon form.

The automation of this numerical method of design optimization is easily implemented and performed by digital computation. The automating of modeling in this manner allows for an accurate level of analysis across thousands of input variables and constraints

Application of linear programming in architectural design can provide an advanced insight to cost patterns and trends that affect the overall quality and success of the built environment. Further adaption of current methods of modeling through linear programming in methods described in this study would allow the introduction and critical analysis of most variables representative of the built environment and architectural practice

Optimal Conditions

- *Budget at a maximum potential*
- *Budget at a minimum potential*
- *Maximum use of material*
- *Conservation of material*
- *Design based on availability of material*

First Cost Analysis

In cases where actual cost of construction cannot be accurately accounted for, value principles or initial upfront cost becomes useful forms of analysis. First cost is the simplest form of economic analysis. The method only accounts for only costs related to the completion design and construction. First cost is linked to architectural and engineering fees, materials and systems for construction, and labour cost. This method does not account for future operating, replacement, or maintenance costs. This method also does not account for performance outcomes or the environmental impact and reuse of the completed environment. First cost as a design method has become more practical in residential construction due to increased oversight in building and energy standards seen in current practice.

This form of analysis is more applicable in projects with little budget flexibility. A flexibility bias limits the adaption of one performance standard over another due to a limiting of materials, systems, and construction methods based solely on perceived ideas of affordability. This appears to be the major limitation of first cost analysis. The using solely of first cost analysis, limits future innovation that offered through more extensive modes of analysis.

Return On Investment

Return on investment analysis expands first cost evaluation by the introduction of operation costs weighted to inflation or discount rate. This methods factors cost relative to life of the product. This method is more comprehensive than first cost analysis. The direct cost of product substitution or design changes are easily accounted for with this methodology. The limitation in this type of analysis comes from a inability to accurately account for indirect costs associated with production substitution.

Life Cycle Analysis

Life cycle cost analysis is a complex method of critical design analysis that looks at the built environment in its totality and incorporates both microeconomic and macroeconomic factors into analytic analysis models. Life cycle analysis compares the cost impacts changes in product, systems, or construction methods over the period of expected life or use. This form of analysis incorporates initials cost with all aspects affecting the owning, maintenance, and operation which occur during the life expectancy of the product or project. This type of analysis also allows for the introduction of nonnumeric qualified factors. These factors relate to the overall environmental impacts and belief structures. Life cycle analysis is applicable to every aspect of design, construction, and operating of the built environment.

Market Trends

Current markets trends place an ever expanding importance in the sustainability of construction and energy thrift of systems used in the construction of new homes and the development of new building technologies. New and improved qualities of existing materials through manufacturing advancements, along with the advancement in building sciences and research are leading professional design to methods to construct, safer, more durable, high performance housing.

Product Substitution

Product substitution is a critical operational aspect of Value Engineering, and should be accounted for in any forms of optimal analysis. Product Substitution involves the changing of one material, or system, for one of less cost. This allows the extending of budget. Materials or systems which are substituted are assumed to equally suitable for purpose.

Limitations To Product Substitution

The greatest limitation to product substitution is in the inability to accurately account for indirect costs. These costs are linked to operation, maintenance, and replacement costs. A change in material or system may also have a increase in labour costs, both direct and indirect.

Optimal Philosophy

This study is the application of optimal design methods applied on domestic residential construction. The emphasis is on the evaluation of existing methods and tools for optimization and the development new adapted methods. The basis points which must be meet are, a value of economy in design, construction, and operation, the ease of construction, the sustainable nature of construction, and the overall security provided in the built environment.

Economy

Systems selected for construction should use a practical commons sense when selecting affordable materials that would be common to the average individual. Economy should be maximized through careful application of budgetary concerns through understanding of limitations and client concerns. The delivered building should offer the greatest return on investment possible to client. Projects should be done in a manner that minimizes the affects of broad macroeconomic market affects.

Buildable

Selected systems should maximize the efficiency of building construction through the minimizing of components needed in construction. Delivered building should have the lowest possible occurrence of needed maintenance, repairs, and component replacements over the useful life of the building. Construction should have some form of modularity through materials and standards use. Delivered building should account for the need for future expansion and retrofits; these should be performable with the greatest amount of ease with the less amount of cost. Erection of building should be able to be performed by any local contractor. Delivered buildings should meet or exceed residential building codes. These functions can be performed through the evaluation of new and existing residential construction methods.

Sustainable

Sustainability defined: the limiting of waste in construction and the minimizing of energy consumption in construction and operation of the built environmental. Materials and systems selection should be based off durability, with the characteristics of longest life and lowest maintenance. Product sourcing should use local suppliers as much as possible out of a sense of greatest economy. Savings in construction is done through the minimal application of durable materials.

Secure

Residence need to display the highest level of protection from environmental and social hazards possible. An understanding of the reasonable care should be applied and practiced. The application of the durable materials and systems should minimize rate of hazards

Simplex Methods
Application To Testing Models

Optimal Conditions

Maximizing of A budgetary Limit
Maximization of Material Quantity

This method provides the maximum utilization of client or project budget. This is performed by the changing of design or construction methods, or by product substitution and or, changes in performance criteria. Optimality is achieved by accounting for numerical variables of materiality and construction cost subject to budgetary limit.

Minimizing Of A Budgetary Limit
Conservation of Material

This method provides a savings in material by minimizing waste.Optimality is achieved by adapting of design and construction methods by imposing limits on material use.

Design Based on Availability of Material

This method maximizes the final composition built environment by use of material availability. Optimality is accomplished by effective use of material subject to quantity limits.

Defining Of Test Assembly

To simplify initial testing a symbolic model was used. A typical wood frame wall assembly with a finite numbers of components was selected. A preferential method was used in the selection of material sub-types for each assembly components.

The selected assembly has three primary components, two by four inch nominal wood or engineered stud, half inch nominal thickness sheathing material, and two and one half inch decking screws. Data reflecting each of the materials properties is then entered into the model. This data records the size of product, unit cost, and quality or grade. During testing it was assumed that the varying material selected for each assembly would be equally suitable for purpose and offers an equal state of value or utility.

Automation of Simplex Methods

The automation of this numerical method of design optimization is easily implemented and performed by digital computation. The automating of modeling in this manner allows for an accurate level of analysis across thousands of input variables and constraints.

Description Of Modeling

Testing and modeling was completed using Microsoft Excel and Solver application. An interactive model was coded using Visual Basic for Applications (VBA) allowing for automation of the iterative process. This allows the benefits of providing a user interface and built in numerical functions which can be called by the user on demand. This also allowed for the storing and recording of determinant and derived data relating to a model function within the model itself. This data can be called for use in future model configurations, simulations, or as a benchmark for post design evaluation.

Properties of each selected material sub-type and defined user constraints are then entered into a series of tableaux or matrices for utilization during simplex iteration. These tableaux display key variables of model parameters, unit cost, minimum quantities needed to complete the assembly, budgetary allocations. The tableaux will also display after reduction, final cost per material, final quantity of each material, or maximum or minimum of a final product. Data is entered and recorded by macro functions called by the user.

The testing model allows for the entry and optimization of three assembly variations at a time, as assembly A, B, or C. This was done to better define a singular field of optimal solutions, allowing quick reference of optimality changes due to material or cost variations

Optimization By Solver Application

Optimization in the model is performed by the use of the Solver application. Model defining parameters are entered into the application from model properties in the tableaux as either as a decision variable or constraint. The application allows for the optimization of an objective function at a maximum, minimum, or user defined target numerical value. The application once started will find either an optimal solution or return an error message. An observed limitation of the Solver application identified during testing was in a form of numerical bias. This was the result of selection of inappropriate variables or constraints. If this condition exists, Solver will converge at a local minimum and provide a biased solution. Testing was completed assuming that model is linear and nonnegative.

Description of Tableau Function

Final Cost Tableau

The total final cost tableau should display after reduction the final cost of each material at a finial quantity at either a maximized or minimized quantity at a budgetary limit. This tableau is read from left to right, and total cost of the assembly can be found by the sum product of each material type final cost. This tableau is subject to budgetary limit, budget allocation per material, the minimum or maximum of material at a selected percentage, and material per unit cost. After reduction this tableau should display a final optimal cost per each component.

Quantity Tableau

The quantity tableau should show the final quantity of each material selected or needed for construction of an assembly. This tableau is subject to budget total, material budget allocation at a selected percentage, and a maximized or minimal material quantity limit. After reduction this tableau should display the optimal quantity of each material subject to defined constraints.

Quantity Limit Tableau

The quantity limit tableau is set as a lower limit of each material component needed to complete the construction of the assembly. This tableau is subject to lower quantity limits and is user defined. For testing quantities needed were three sheet of half inch plywood, eight two by four studs, and 144 mechanical fasteners. This is a user defined tableau and is static and remains unchanged after reduction.

Material Budget Allocation Tableau

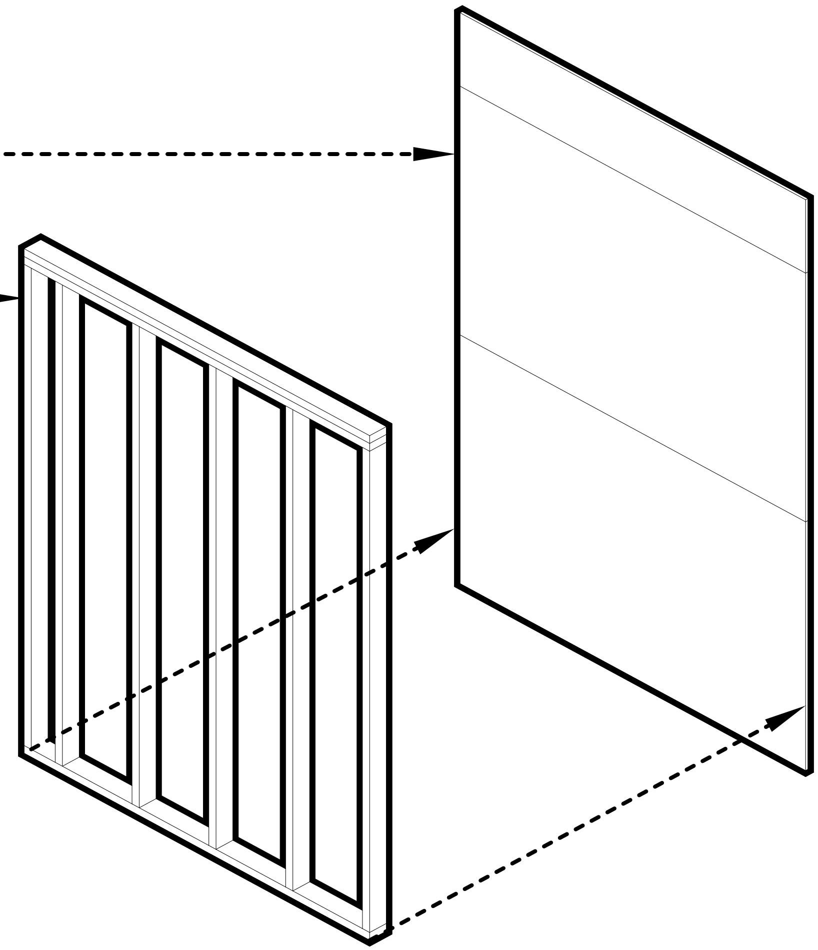
The material budget allocation tableau should display budget per material subject to a user defined percentage allocation. This percentage is required to be high enough to meet minimum requirements of material quantity. This table is solely used when maximizing material to a budgetary limit and not used for a minimal material per budget calculation. It was observed that a weighting of budget per individual material was needed to address mathematical bias due to price point. It was found without the limiting of budget per material, that modeling would favor lower cost or easily dividable price points. This tableau is subject to budgetary limit, material lower quantity limits, and material unit cost. This tableau is user defined and remains unchanged after reduction.

Unit Cost Tableau

The unit cost tableau should display the unit cost per each selected material. These costs are representative of local supplier cost and are entered by user defined preferences. This tableau is used in the calculation of final cost total, material budget allocation per material, and final cost of a maximized of minimized quantity per each material. Data in this tableau is entered from stored price data. This tableau is user defined and remains unchanged after reduction.

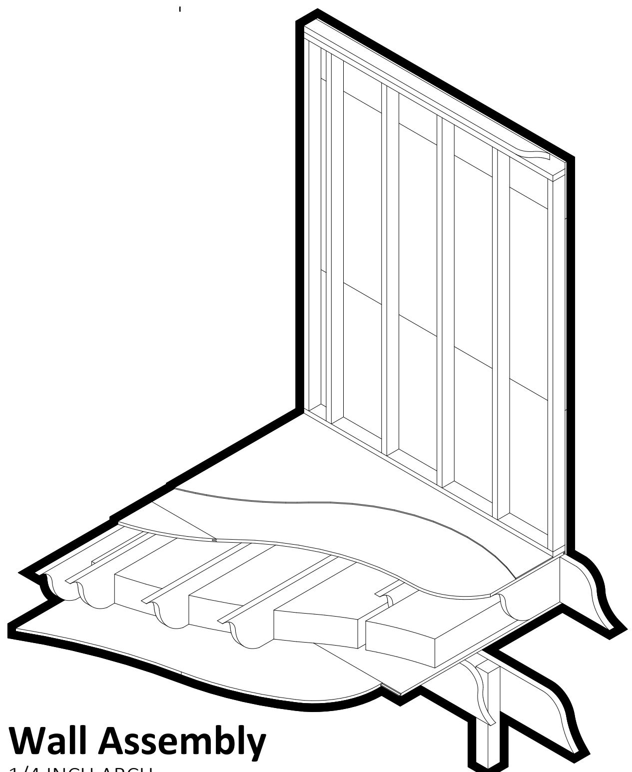
Test Assembly

Material Table	
Type	Quantity
1/2" Plywood	3
2X4 Studs	8
2-1/2" Screws	144



Exploded View

NOT SCALED



Wall Assembly

1/4 INCH ARCH

Maximizing of A Budgetary Limit

Material Maximized by Optimal Iteration

Maximization of Material Quantity

This method provides the maximum utilization of client or project budget. Optimality is achieved by accounting for numerical variables of materiality and construction cost subject to budgetary limit.

This method is the most common scenario that a designer, contractor, or tradesman, will encounter is the fitting of construction or system to a budgetary limit. This Budgetary limit can be either a maximum or minimum target.

Description of Method

Using the wall assembly as the testing model, optimal related conditions would occur at material maximum with the highest rate of budget utilization.

Application of Method

This method will produce a maximum optimal material quantity at a budgetary upper limit, subject to material quantity lower limits and budgetary upper limits.

It should be noted that care should be practiced in the selection of proper constraint or model variables. Weighting is required with this method of simplex reduction in order to resolve at an unbiased optimal point. Without the weighing of budget, reduction will resolve at a local minimum, or favor materials with lower cost with easily dividable numerical values. Weighing is achieved by the allocating of budget per material.

Model At Maximum

Objective Function *Less than equal to buget maximum*

Px+Sx+Fx ≤ Budget Maximum

Subject To *Greater or equal to material lower limits*

Px ≥ Pq
Sx ≥ Sq
Fx ≥ Fq

And *Less than equal to material allocation*

Ptc ≤ Plywood Budget Allocation
Stc ≤ Studs Budget Allocation
Ftc ≤ Screws Budget Allocation

And *Less than equal to Budget Maximum*

Budget ≤ Budget Maximum

Plywood	P
Studs	S
Screws	F
Quantity	q
Total Cost	tc

Budget Allocation

Budget material allocation can be set based on two methods, material lower quantity, and material percentage allocation.

Budget By Needed Quantity

Budget set by a minimum quantity is produced by simple multiplying of needed material by the unit cost. This will return a lower limit for the model budget.

Limitations

The issue with this method is that it can only be used to produce a minimum return. Use in maximum return will favor local minimums and return a biased optimal point.

Budget By Weight Percentage

The method will produce a maximum optimal quantity at the highest allowable rate of budget utilization. Percentages are calculated by the user based on the desired returns.

Limitations

The issues with this method are in the correct selection of budget allocation. Budget allocation will change based on case. It is however possible to use regulatory and size limitations to evaluate the budget allocation. This is the most favorable method to use to find an optimal maximum material quantity.

Results At Maximum

Budget	297 USD

Material Quantity

	Before	After
Plywood	3	15
Studs	8	48
Screws	144	212

Material Budget Allocation

	Before	After
Plywood	139.95	134.85
Studs	139.95	138.72
Screws	14.84	14.84

Budget Utilization

Plywood	96%
Studs	99%
Screws	100%

Overall Utilization	97.10%
Unutilized	2.9%

Minimizing of A Budgetary Limit

Material Minimized by Optimal Iteration

Minimization of Material Quantity

This methods provides a conservitive utilization of client or project budget. Optimality is achieved by accounting for numerical variables of materiality and construction cost subject to budgetary limit.

Application

This method will return a minimum quantity of material subject to material lower limit, and budget maximum limit. The returned budget can be at a maximum budgetary upper limit. The normal return will be below the budget maximum limit. This can demonstrate the feasibility of budget selection for one assembly over another by having a cost higher or lower than expected limits.

This method is useful in the production of lower budgetary limits which can be applied in further testing.

Model At Minimum

Objective Function *Less than equal to buget maximum*

$$Px+Sx+Fx \leq \text{Budget Maximum}$$

Subject To *Equal to material lower limits*

$$Px = Pq$$
$$Sx = Sq$$
$$Fx = Fq$$

And *Less than equal to Budget Maximum*

$$\text{Budget} \leq \text{Budget Maximum}$$

Plywood	P
Studs	S
Screws	F
Quantity	q
Total Cost	tc

Results At Minimum

Budget		297 USD

Material Quantity		
	Before	After
Plywood	3	3
Studs	8	8
Screws	144	144

Material Budget Allocation		
	Before	After
Plywood	26.97	26.97
Studs	23.12	23.12
Screws	10.08	10.08

Budget Utilization	
Plywood	100%
Studs	100%
Screws	100%

Overall Utilization	20.25%
Unutilized	79.75%

Conclusion of Budgetary Methods

It was found that each of these two budgetary methods will, when correctly configured, will produce a optimal return. This return can be at either a maximum or minimum target.

Design Based on Optimal Returns

This method uses the optimal returns of cost and quantity generated by both budgetary methods. This allows the analysis of design composition to test the feasibility of budget reallocations. This is done to achieve a higher rate of utilization in the design by utilizing waste products. Waste products have the potential to increase the success of construction.

It must be noted that building products cannot be purchased in fractional amounts. Any unused materials are considered waste product if not utilized in the design.

Application

Once the defined material quantity is satisfied, any excess material or budget can be reallocated to increase design performance. This reallocation can be in the form of, material quality increases, material quantity increases, better systems or methods, or increase in building footprint.

Coverage Limits

By introducing a minimum coverage variable into modeling it allows the calculation of waste ratios based on actual purchased, and need material coverage. This ratio is subject to material quantity lower limits and a budgetary maximum limit.

The utilization of waste products can be demonstrated by using the wall assembly test unit. The needed actual amount of plywood needed is eighty sqaure feet, or 2.5 sheets. The purchased amount is ninety-six square feet, or three sheets. Each sheet is four by eight feet and has thirty-two square feet of coverage. *(see figures on page 21)*

Limitations to Reallocation

The process to utilize waste materials in the design is subject to structural and regulatory limitations. This limitation may make it unfeasible to reallocate overages without incurring cost both directly and indirectly.

Regulatory limits

The utilization of waste material and budget overages become subject to regulatory limits which define the allowable use of each material. Each material or method of construction is dependent on spacing or composition of the structure.

Using the wall assembly, the use of excess plywood is dependent on spacing of the studs. For a two by four inch stud this would be a maximum allowable spacing of eighteen inches on center for unrated studs. This spacing is set by code. Since spacing is dictated and not arguable, the use of plywood overage would possible result in the need to purchase more studs to allow its use. This would also result in a need to purchase more fasteners and higher labour costs, from expansion of construction

Size Limitations

Since each piece of plywood is two foot by four foot, framing will have to fall as to have framing support the edges of the plywood. Changes to use a half sheet or less of plywood will dictate a change in framing or bracing. Design should utilize the prescribed size of each material to its fullest extent when possible.

Results At Maximum

Budget	297 USD
Plywood Per Sheet Coverage	32 SQFT
Needed Coverage	80 SQFT
Fixed By Purchase	480 SQFT
Needed Quantity	2.5 Sheets
Quantity Fixed By Purchase	15 Sheets
Plywood Unit Cost	8.99 USD
Overall Cost	134.85 USD
Utilization	16.6%
Unutilized	83.4%

The calculated waste in the design is 400 square feet, or twelve and half sheets of plywood, at 112.38. This at a maximum cost of 288.41 dollars would be 38.9 percent of total budget. Potential exist in the adaption of design to use this overage of budgetary of material expenditure to expand design or reallocate products to other aspects in the design.

Results At Minimum

Budget	297 USD
Plywood Per Sheet Coverage	32 SQFT
Needed Coverage	80 SQFT
Fixed By Purchase	96 SQFT
Needed Quantity	2.5 Sheets
Quantity Fixed By Purchase	3 Sheets
Plywood Unit Cost	8.99 USD
Overall Cost	26.97 USD
Utilization	83%
Unutilized	16.7%

The calculated waste in the design is sixteen square feet of plywood, or half a sheet, at 4.50 dollars. This at a minimum cost of 60.17 dollars would be 7.5% of the total budget.

Limits Defined by Rates of Utilization

This method uses the rate of utilization to find dependant materials. Materials with a higher rate of utilization will dictate the use of materials with a lower rate.

Utilization Rate

Using the wall assembly test model as example, with a conservative budget, at a optimal minimum, we can calculate material utilization rates.

Since the rate of utilization for the two by four studs and screws are at 100%, the use of waste plywood is dependent to the other products. This method allows for the analysis of material usage accuracy in each design. This demonstrates any feasibility to changes.

Limitations

It should be noted that it may not feasible to utilize waste products. This method should be coupled with life cycle analysis to produce a accurate cost profile representative of design changes.

Conclusion

The method provides to be the most useful in the directing of critical architectural design. When complied with budgetary methods, it allows for the accurate accounting of both externally fixed material and regulatory exogenous variables, and designer defined internal endogenous variables. The ability to express most, if not all design variables in a single generative model, allows for the production of the highest rate of optimal returns to architectural design problems. This accuracy in modeling provides solutions sensitive to both economic conditions and waste products. The application of linear programming, in architectural design, can provide an advanced insight to cost patterns and trends that affect the overall quality and success of the built environment.

Results of Utilization at Minimum

Budget	297 USD

Material Quantity	
Plywood	3
Studs	8
Screws	144

Quantity	Needed	Fixed By Purchase
Plywood	2.5	3
Studs	8	8
Screws	144	144

Material Utilization	
Plywood	83.3%
Studs	100%
Screws	100%

Waste Values	
Plywood	~4.50 USD
Studs	0
Screws	0

Project Justification

I expect a personal level of quality in my work. This quality is a value of personal doctrine in my work. The development of affordable, quality housing serves two functions. One, is that is serves a purpose in a community, helping develop an economic base and support social health. Secondly, it provides an economic incentive to designers and contractors to produce work.

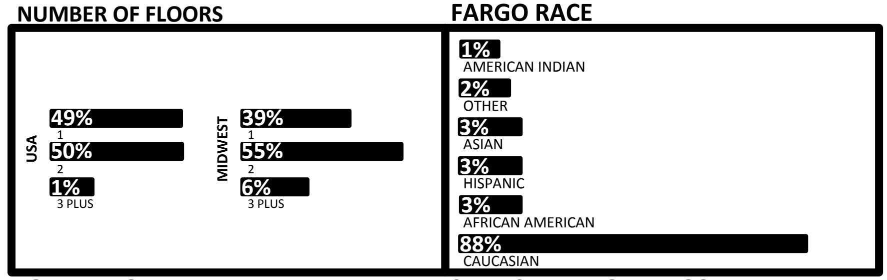
The health of economics is a pattern of repeating cycles of successful development and extreme downturns. The understanding of value economic s allows homeowners, architects, and contractors to lessen the impact of market function on their homes or projects. By understanding the cost versus a value in residential construction allows for a savings in money, time, and resources.

Value is defined as an important variable in critical architectural design. The researching of this variable in a critical manner may add to the scholastic and professional body of knowledge. This project is an attempt to bridge this concept across a broad spectrum of professional fields. The savings in residential construction through optimization of design methods justifies the further adaptations and development of this study.

Contextual Research

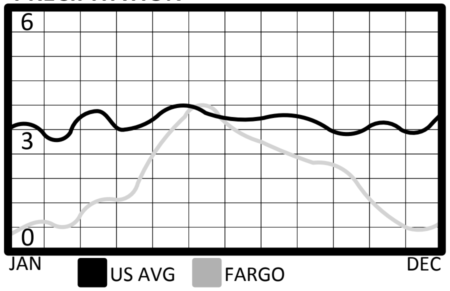
Characteristics

These graphics represent metric data of housing. This information was completed to understand and develop project characteristics. This relates to both spatial and demographic data selection. The data is presented with different characteristics for each and is noted. It was decided to use data representative of Midwestern contractor built housing.



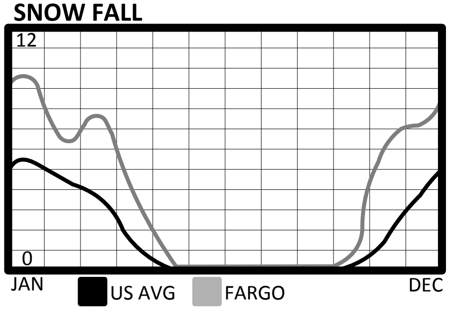
Site Climate Data

PRECIPITATION



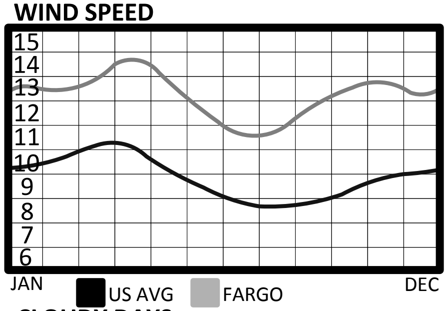
The Northern Plains has a lower perception rate than the US average

SNOW FALL



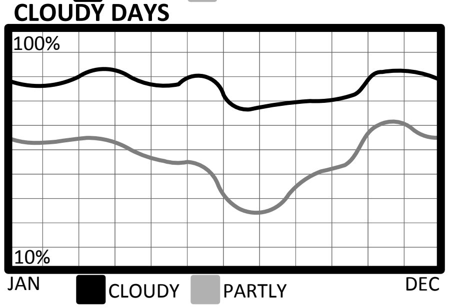
The level of snowfall in the Northern Plains ranges from average rates matching the rest of the northern portions of the US and Canada, but can have higher than average any year. The colder temperatures and northern location means that snow remains on the ground for a longer period of time.

WIND SPEED



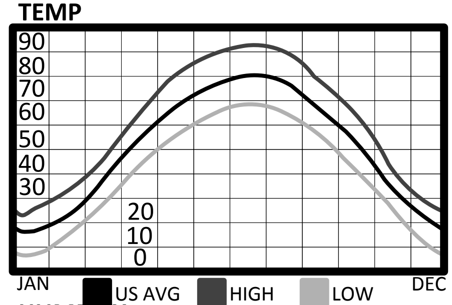
The flat plains and low tree coverage of North Dakota all winds to pass at a high speed across the terrain. These winds are generally stronger in the winter months. This can lead to wind chill and hazardous conditions. See Page 32 for wind accross site,

CLOUDY DAYS



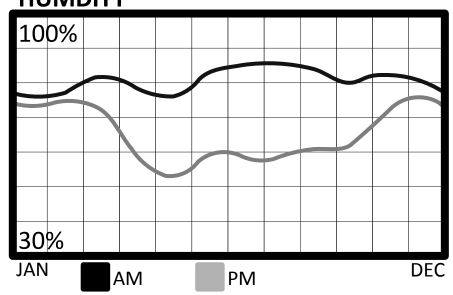
Fargo has a higher number of cloud cover days. The months of November and December have the highest number of overcast days. June through September offers are most likely months for a clear sky to occur.

TEMP



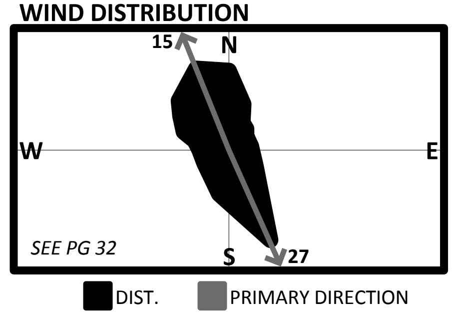
The temperatures of the upper northern plains fluctuate from higher nineties to temperatures of minus forty. The temperature swing can be as much as 130 degrees. This cycling of freeze and thaw create unique building conditions. Materials and methods need proper thermal protection and durable materials.

HUMDITY



The Fargo area has normal humid conditions, which match US average conditions. July and August provide to be the most humid months of the year with large diurnal temperature swings.

WIND DISTRIBUTION

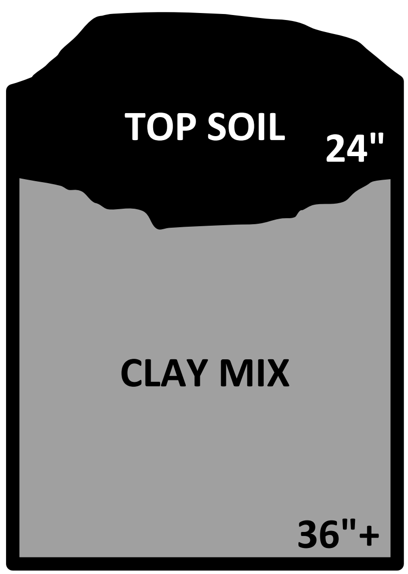


Primary wind directions occur from the northwest or south east. Northwestern winds have an average speed of twenty-seven miles per hour. Southeastern winds have an average wind speed of fifteen miles per hours. It is not unusual for gust of forty miles an hour or more.

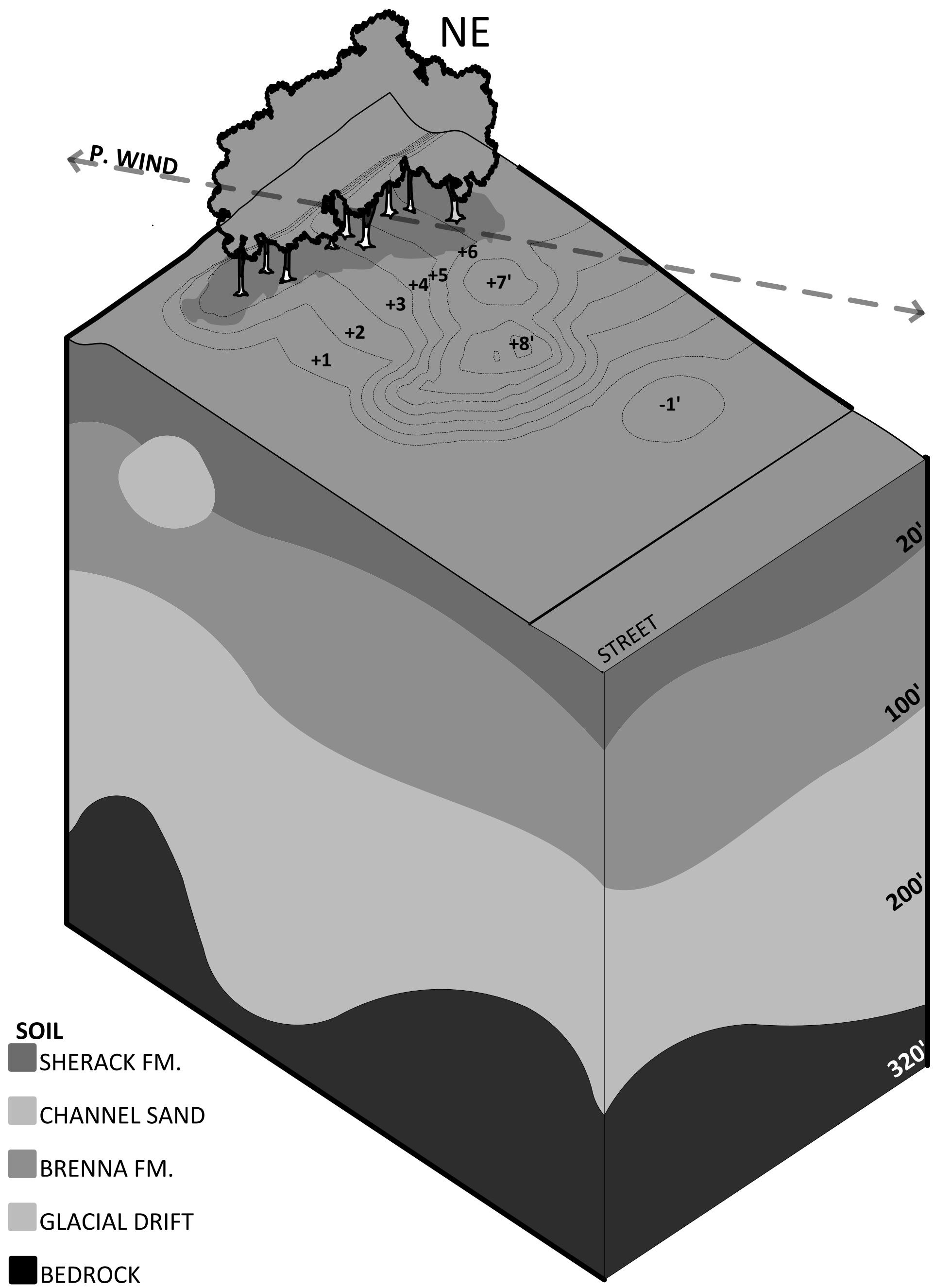
Site

Soils

The Northern Plains has a lower perception rate than the US average. The soil of the area is high in clay. The non permeable soils have lower rates of absorption. This higher rate leads to damper soil conditions and areas more prone to flooding. The top soil ranges from eighteen inches to thirty-two inches, after which is a mix of clay and aggregates. The top soil of the Red River Valley has the highest quality growing soils globally. Bedrock is 200 to 320 feet below ground.



SOIL TEST



Space Allocation

Description of Space

The project is a mid size residential structure, of one to two stories. The structure is not to exceed 2400 square feet. The residence is a single family home. The layout consists of at least two bedrooms, with a minimum square footage of seventy and a maximum of 250 square feet. Bathrooms at minimum will be one full bath, located adjacent to bedrooms, and half bath located near the family space. General use spaces are a family space of 550 square feet, and a kitchen of 550 square feet. The entry space will be adjacent to the kitchen or family space. A mechanical room is adjacent to the kitchen and half bath.

Primary Spaces

Master Bedroom

Bedroom Two

Full Bath

Half Bath

Kitchen

Family Space

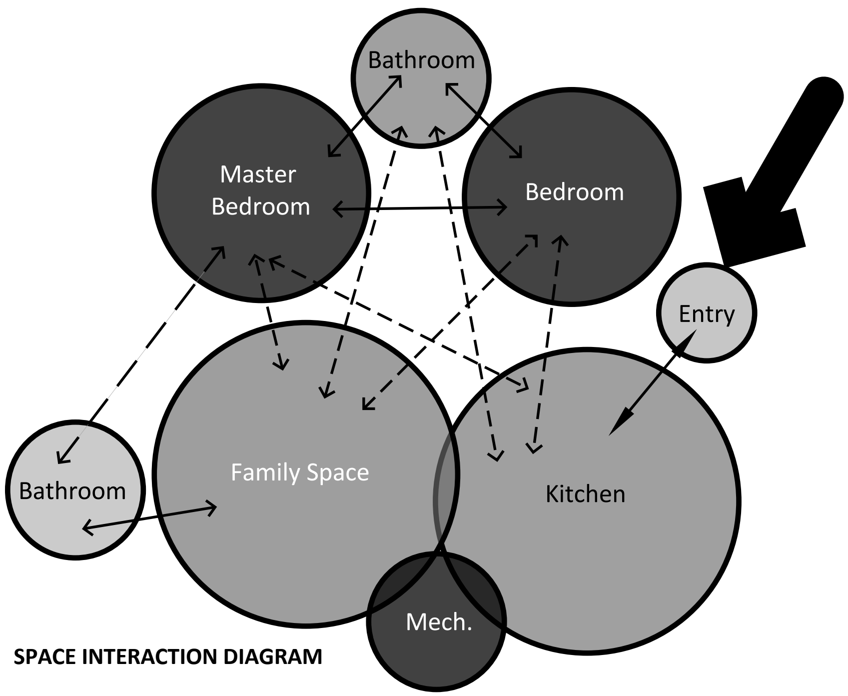
Mechanical

Entry

SPACE ALLOCATION TABLE

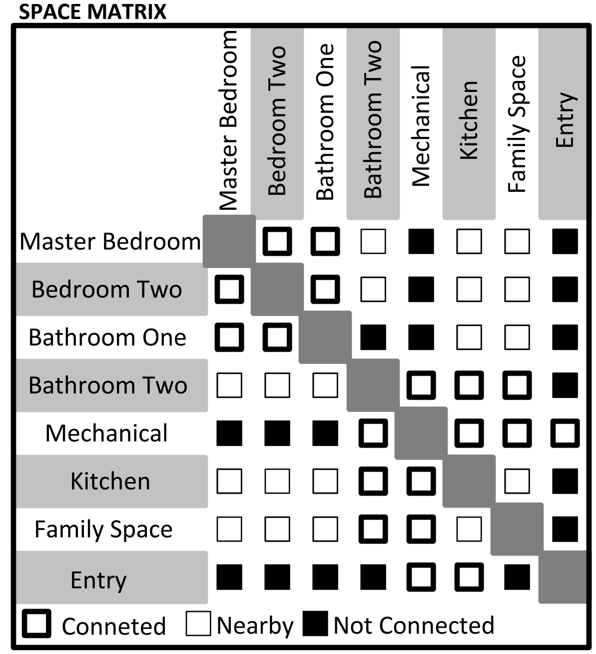
	Min		Max	
Master Bedroom	100	*11.91%*	250	*10.87%*
Bedroom Two	100	*11.91%*	250	*10.87%*
Bathroom One	70	*8.34%*	150	*6.52%*
Bathroom Two	*	*8.34%*	100	*8.34%*
Mechanical	70	*8.34%*	150	*6.52%*
Kitchen	70	*8.34%*	550	*23.91%*
Family Space	250	*29.78%*	550	*23.91%*
Entry	70	*8.34%*	100	*8.34%*
Circulation 15%	109.5	*13.04%*	300	*13.04%*

**Minimum Sqaure Footage Set By IBC R.304.2*
**Garage is not accounted for in table*



SPACE INTERACTION DIAGRAM

SPACE MATRIX



Base Modeling Metric Data

This data represents the base parameters for the study's project test models. It is representative of the combined research data.

Total Max Square Feet

2400

Cost Per Square Foot -USD

112

Clients Yearly Income-USD

53039

Amount Available for Construction-USD

14850.92

**28% of Yearly Income*

Available Per Month-USD

1237.58

**14580.92/12Months*

Lot Size-SQFT

22000

Lot Purchase Cost-USD

55000USD

**(2.50 USD Per Square Foot 22000(2.50)*

Monthly Mortgae Payment-USD

1207.03

**268800 at 3.5% 30 Years Fixed*

Budget Margin-USD

30.55USD

**1237.58-1207.03*

Budget Utilization

97.53%

**(1207.03/1237.58)(100)*

30 Year Mortgage Cost-USD

433747USD

**268800+164947 (Principal+Interest)*

Project Actual Value-USD

323800

**268800+55000 (Principal+Lot Cost)*

Combined Tax rate

1.1%

2 Year Tax Exemption for New Construction-USD

150000

First Year Tax

1911.8

**323800-150000 =173800(.11)*

First Year Mortgage Interest Payment-USD

9325.77

First Year Mortgage Principal Payment-USD

5158.62

Deductable Amount-USD

11237.57USD

**9325.77+1911.8*

Principal Over 30 Years-USD

8960

**268800/30*

Total Cost Over 30 Years-USD

14458.23

**20.433747/30*

Maximum Allowance Per Square Foot-USD

116.58USD

Maximum Square Footage at 112USD

2498

Performance

Performance Criteria

Optimal Philosophy

This study is the application of optimal design methods applied on domestic residential construction. The emphasis is on the evaluation of existing methods and tools for optimization and the development new adapted methods. The basis points which must be meet are, a value of economy in design, construction, and operation, the ease of construction, the sustainable nature of construction, and the overall security provided in the built environment.

Economy

Systems selected for construction should use a practical commons sense when selecting affordable materials that would be common to the average individual. Economy should be maximized through careful application of budgetary concerns through understanding of limitations and client concerns. The delivered building should offer the greatest return on investment possible to client. Projects should be done in a manner that minimizes the affects of broad macroeconomic market affects.

Buildable

Selected systems should maximize the efficiency of building construction through the minimizing of components needed in construction. Delivered building should have the lowest possible occurrence of needed maintenance, repairs, and component replacements over the useful life of the building. Construction should have some form of modularity through materials and standards use. Delivered building should account for the need for future expansion and retrofits; these should be performable with the greatest amount of ease with the less amount of cost. Erection of building should be able to be performed by any local contractor. Delivered buildings should meet or exceed residential building codes. These functions can be performed through the evaluation of new and existing residential construction methods.

Sustainable

Sustainability defined: the limiting of waste in construction and the minimizing of energy consumption in construction and operation of the built environmental. Materials and systems selection should be based off durability, with the characteristics of longest life and lowest maintenance. Product sourcing should use local suppliers as much as possible out of a sense of greatest economy. Savings in construction is done through the minimal application of durable materials.

Secure

Residence need to display the highest level of protection from environmental and social hazards possible. An understanding of the reasonable care should be applied and practiced. The application of the durable materials and systems should minimize rate of hazards

Measurable Optimal Conditions

- *Budget at a maximum potential*
- *Budget at a minimum potential*
- *Maximum use of material*
- *Conservation of material*
- *Design based on availability of material*

Benchmark Standards

2015 International Building Code

2015 International Residential Code

2017 North Dakota Building Code

ADA 504

ASTM E2156.34707 Evaluation of Perfromace Standards

ASTM E917-15 Life Cycle Cost

Process Documentation

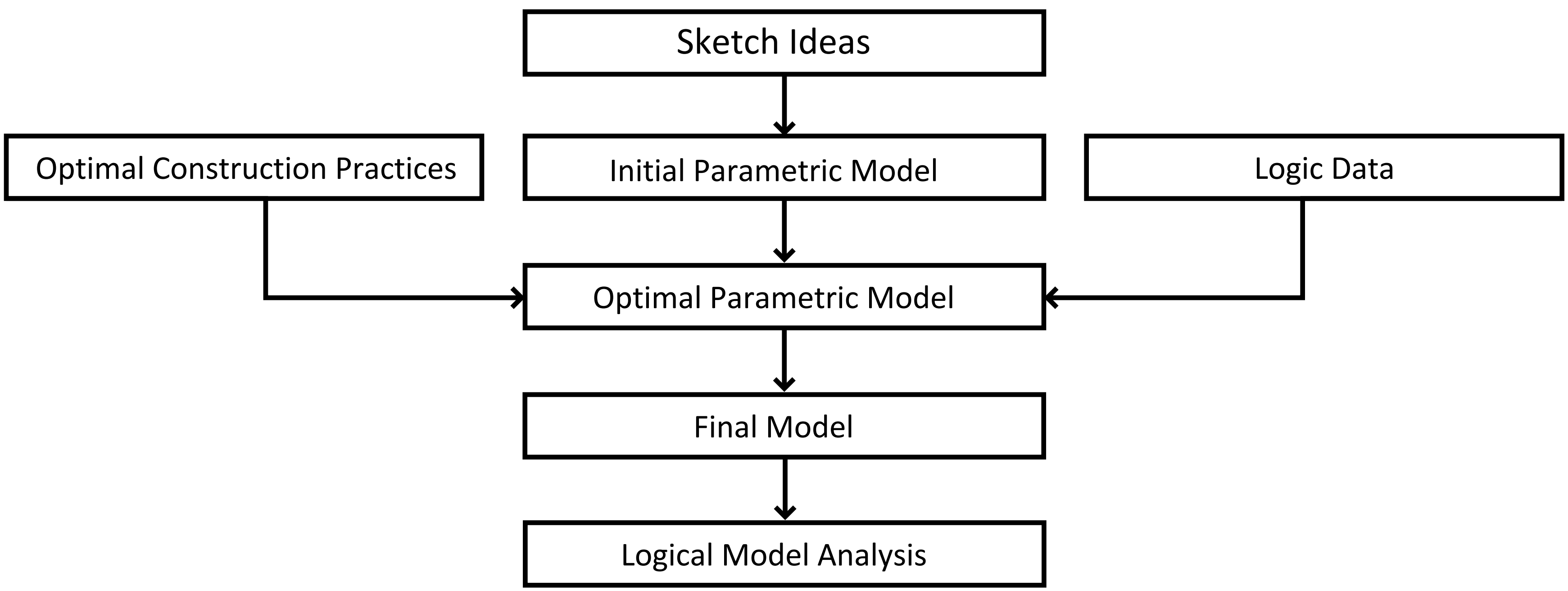
Experimental Architecture

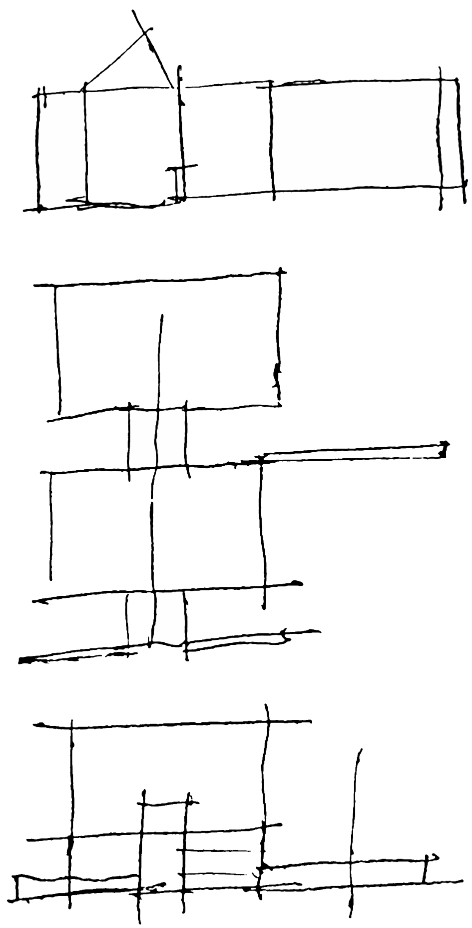
Development of Design

The initial design work was completed without regard to optimal philosophy. This was done in order to preserve aesthetic qualities present by innate interactions of volumes and style. The design was translated from sketches to a parametric model. Once completed, optimal logic is applied to the initial parametric model.

Modeling the design in this manner provides a test bed for the application of optimal design practices which can be translated into analytical methods. The manually optimal design is considered ideal, It remains unchanged as a benchmark.

Experimental Architecture / Design Process





Initial thumbnails

What is Optimal Design

An optimal design will utilize a maximum amount of purchased needed material while minimizing waste, construction cost and time.

Adjustments to design parameters can be done in a manner to either utilize a budget or material usage target. Research focus and design development should identify optimal methods of and design and analytic tools.

Methods and Materials

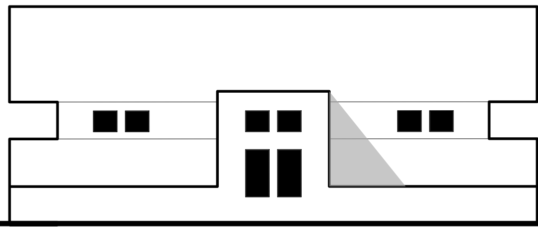
Each construction method or building material or systems, have limitation which constrain a design.

Identified Constraints:

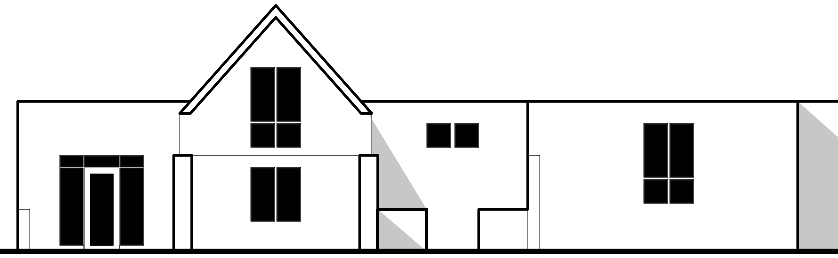
• Structural / Code
• Budget / Cost
• Available Stock X, Y, and Z
• Client Demand

Each of the properties has a logical relationship to each other, and can be mapped to develop a graphical method of optimal relationship.

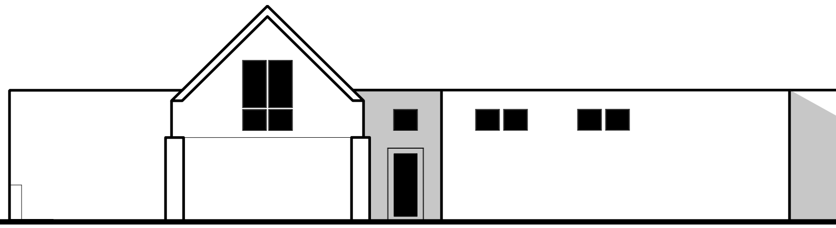
Design, February 2018



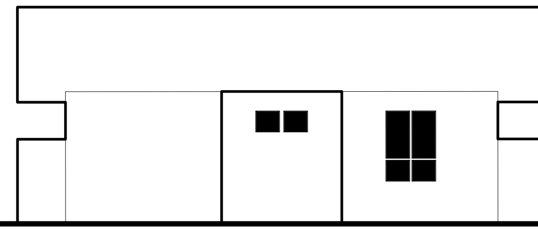
South Elevation 1



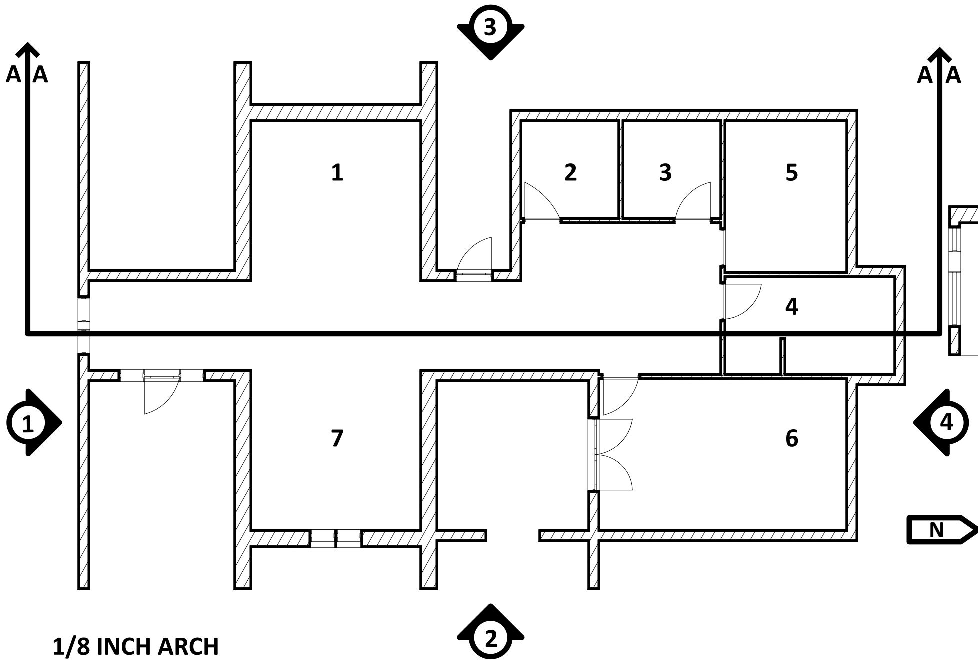
East Elevation 2



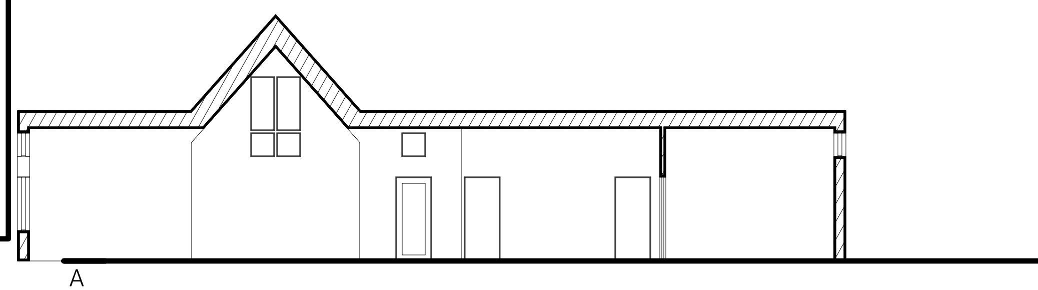
West Elevation 3



North Elevation 4

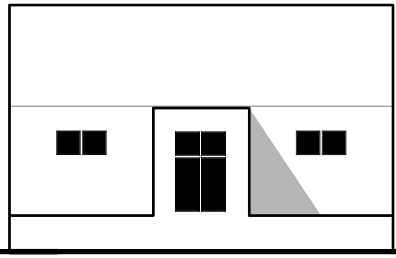


1/8 INCH ARCH

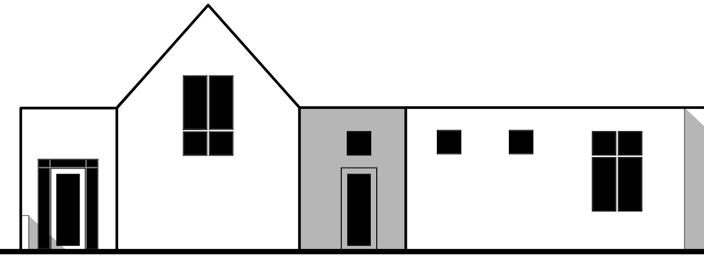


Kitchen	1
Mechanical	2
Half Bath	3
Full Bath	4
Bedroom	5
Master Bedroom	6
Living / Dining	7

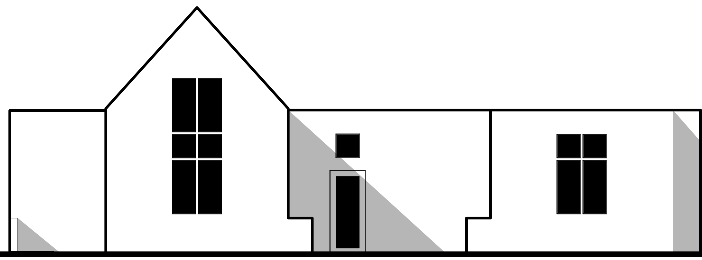
Design, March 2018



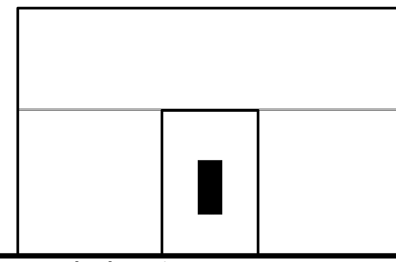
South Elevation 1



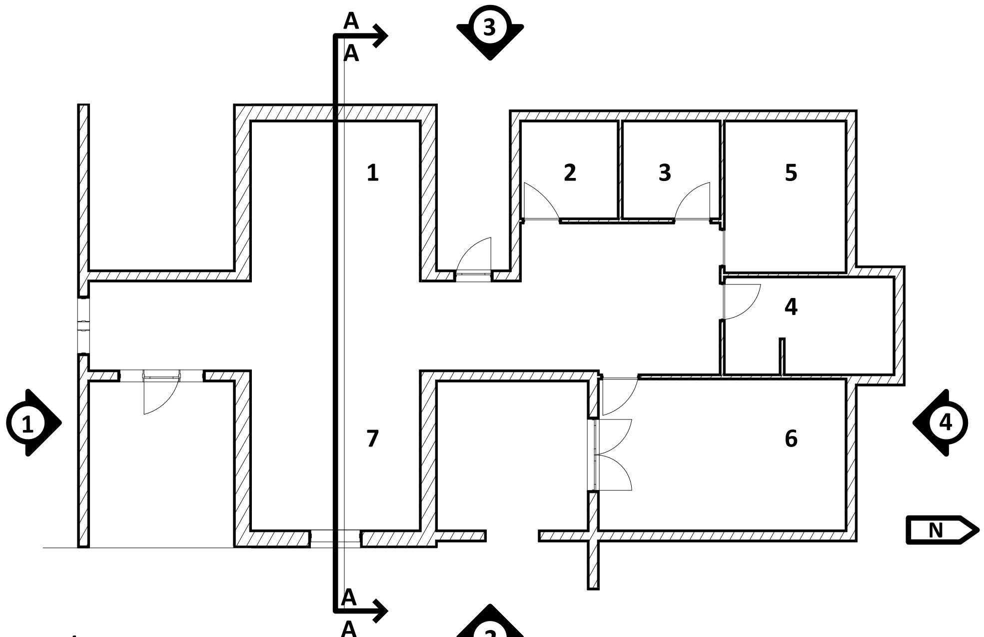
East Elevation 2



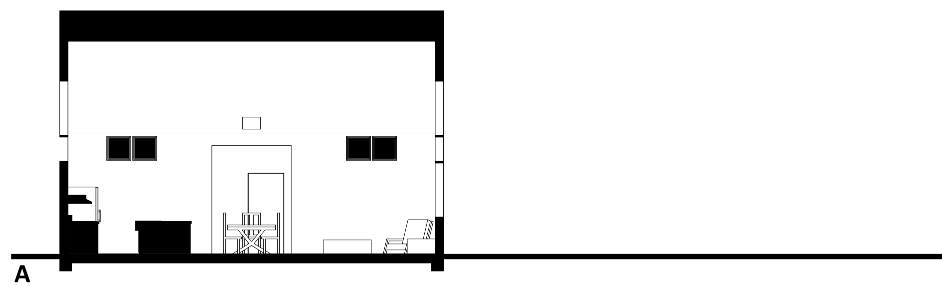
West Elevation 3



North Elevation 4



1/8 INCH ARCH



Kitchen	1
Mechanical	2
Half Bath	3
Full Bath	4
Bedroom	5
Master Bedroom	6
Living / Dining	7

Routes to Optimal Design and Construction

General Practices

Use available stock as much as possible, limiting when possible the use of custom applications.

Use materials in a manner that minimizes or eliminates cuts and excess milling. The minimizing of field cuts minimizes construction time, construction cost, and material waste.

Design and building systems should be simplified to the basic, acceptable elements needed for the completion of construction.

Determine the dominant measurement for each assembly or construction type. This is accomplished through logic mapping. The standardization of design to a dominant measure will allow for a high rate of optimality.

Construction should be performed in a method that minimizes wasteful practices, and use quality as a doctrine throughout.

Design using gird that reflects the dominant measurements. In nominal materials available within this occurs at one foot vertical and four foot horizontal. This design by grid is historically seen within practice.

Limitations to Optimality

The main limitation to generation of a optimal solution is the correct defining and correlation of variables and objectives. The correct definition of variables is important, and needed in the formation of a prescriptive informative model.

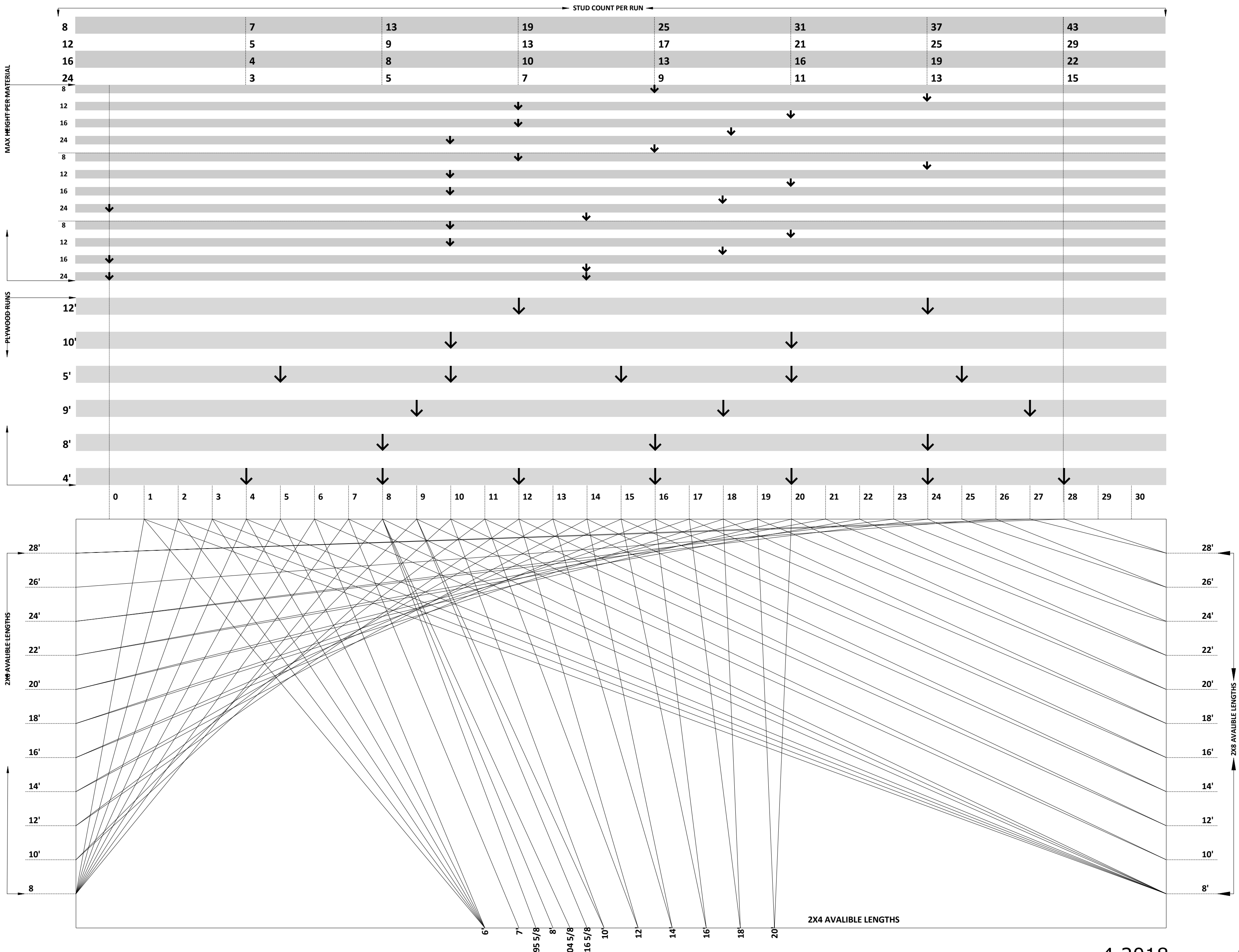
Logic Mapping

Uses common properties shared by each material or system. Mapping should allow for the identification of further constraints, or limitations to an optimal design return. Mapping allows for the development of common profiles of design and a field of possible solutions.

A Residential Contraction Profile may show the mapped relationships between:

- **Cost / Unit Cost**
- **Material Size / Available Stock**
- **Maintenance Cost / Lifetime**
- **Acceptable Construction Methods / Spacing, Loads**

2X4 Framing Logic Mapping



4.2018

Four Methods of Optimal Analysis

Manual, Common Sense
Manual application of optimal practices without upfront numerical analysis, optimization by doing. Preformed on the fly adjustment to effect an change in performance or quality.

Linear Programming
Uses Linear Algebra in a graphical method to define a field of optimal conditions bounded by linear arguments reflecting model constraints.

Simplex Analysis
Uses Simplex Algorithm to mathematically solve a system of linear arguments defined by user input.

Logic Modeling
Uses automated program defined by construction assembly type. Uses logic gates and logical statements to generate an optimal condition.

Manual, Common Sense
Inputs to system

- **Acceptable uses of Materials**
- **Understaning of Construction Systems**
- **Review of Code**
- **Quatlity Assurance**
- **Construction Practices**

Optimal Practices are applied during design and construction.

Known Issues:
Manual application provides little or no foresight to complicated issues during design and initial construction phases.

Individuals involved in work need a high level of practical constructio nknowledge and optimal practices.

Have a need to perform post occupancy to evaluate performance.

Linear Programming

Inputs to system

- **Acceptable uses of Materials**
- **Understaning of Construction Systems**
- **Review of Code**
- **Quatlity Assurance**
- **Construction Practices**
- **Cost Profiles**
- **Economic Analysis**

Linear Programming uses a system of linear equations from logic mapping to numerate an optimal return subject to an Objective Function.Linear methods can be applied as either as generative process or as post occupancy numerical analysis.Linear methods can be applied as either as generative process or as post occupancy numerical analysis.

Objective Function:

An Objective Function is any metric chosen by a designer which they want to optimize, or desired outcome.

Logical Operators:

- **Equal To**
- **Less Than**
- **Greater Than**
- **And**
- **Or**
- **Dose Not Equal**

Each linear argument is resolved to a matching logical operator selected by the user. This controls the range of return.

Linear Equation:

=Value A + Value B >= Objective Function

Known Issues:

Manual application provides little or no foresight to complicated issues during design and initial construction phases.

Individuals involved in work need a high level of practical construction knowledge and optimal practices.

Have a need to perform post occupancy to evaluate performance. Linear methods can be applied as either as generative process or as post occupancy numerical analysis.

A need to develop and understand the working mathematics of Linear Algebra used in analysis.

A need to find numerically similar attributes of the materials and processes used. Linear Analysis works best in systems with fewer linear equations.

Linear programming cannot account accurately for functions that are exponential.

A need to select appropriate model limits and constraints. The choosing of incorrect or poorly weighted constraints can result in false optimal or resolution to a local minimum. Linear reduction tends to favor materials with sizes and prices that easily dividable or of lower cost.

Advantages:

Linear Programming can provide in an accurately weighted model an optimal condition, numerically.

Methods can be used in programmed automated systems.

Simplex Analysis

Using Solver Application

Inputs to system

- **Acceptable uses of Materials**
- **Understaning of Construction Systems**
- **Review of Code**
- **Quatlity Assurance**
- **Construction Practices**
- **Cost Profiles**
- **Economic Analysis**

Automation of Linear Programming

Simplex optimization provides the optimal method for solving linear equations presented by critical architectural design. The Simplex method of solving linear programming problems returns a optimal solution in to a user defined objective function by iteration of designer selected decision variables. This performed by means of Gaussian reduction and back substitution to return a final optimized tableau in optimal resolved form.

The automation of this numerical method of design optimization is easily implemented and performed by digital computation. The automating of modeling in this manner allows for an accurate level of analysis across thousands of input variables and constraints. Optimization in the model is performed by the use of the Solver application. Model defining parameters are entered into the application from model properties in the tableaux as either as a decision variable or constraint. The application allows for the optimization of an objective function at a maximum, minimum, or user defined target numerical value.

Known Issues:

Simplex Analysis has the same known issues as traditional Linear Programming methods.

Advantages:

Automation of modeling allows for quick, accurate iteration of model variables.

Allows for the programming and storing of model variables with a single, searchable database.

Logic Modeling

Inputs to system

- **Acceptable uses of Materials**
- **Understaning of Construction Systems**
- **Review of Code**
- **Quatlity Assurance**
- **Construction Practices**
- **Cost Profiles**
- **Economic Analysis**

Linear Programming and Simplex analysis are highly limited when deriving system attributes that are numerically similar. Many of the attributes of residential construction do not share an appropriate compatible numerical variable.

A Need exist for the accurate accounting of these non conforming variables present in residential construction.

System analysis is performed by iteration of model variables through asystem of Logical Statements which generate a series of optimal assemblies.

Linear Argument:

IF A=B, Then C, ETC

The logic modeler uses the same basic logical operators as Simplex Analysis. It however, expands to allow the nesting of multiple functions within one logical statement. Each variable is dynamically chained to each in the assembly.

Importing of Logic Data:

Data is imported into the model is derived from logic graphics; which display the numerical and non-numerical interactions of construction methods, materials, and design principles. Each interaction is then converted to a logical statement.

Known Issues:

This type of modeling, though hyper accurate, requires an excessive time of upfront programming. The development of each logical statement requires an individual with a high knowledge of model parameters and system inputs.

Advantages:

Logical Modeling allows for the quick, accurate, iteration of model variables based on user controlled input and programmed variables.

This type of modeling allows for the accurate accounting of material use and waste product, with an attached cost profile.

Logical modeling allows for the introduction of dynamic shape data, allowing the quick and accurate output of a vector graphic with accurate dimensions.

Possible Future Implications for Practice:

Logic Modeling and the linking of shape data to numerical analysis, allows for the introduction of advanced formulas relating to structural design and environmental systems.

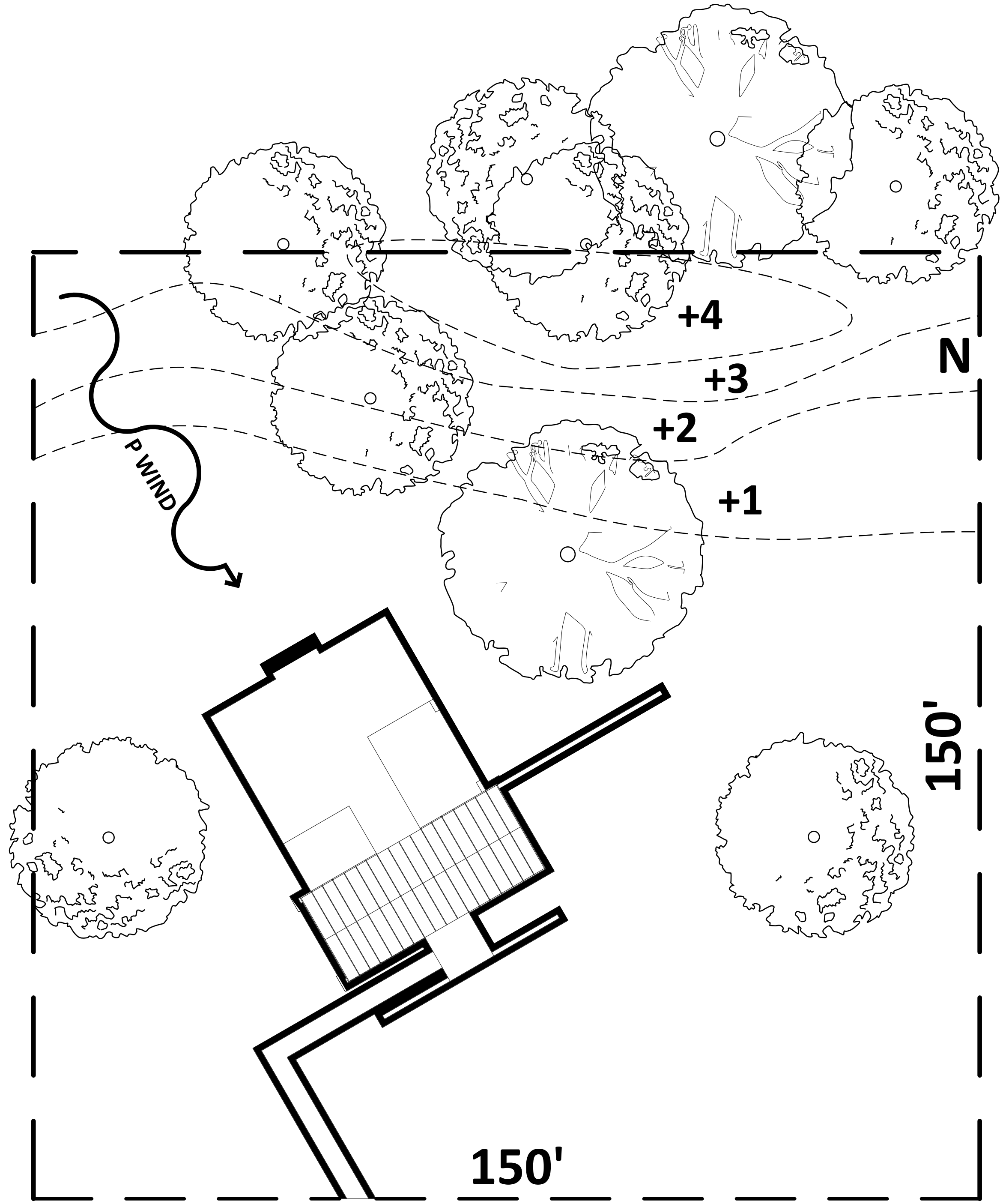
This type of model provides economic sensitive data, and allows the introduction of non-numerical attributes relating to client beliefs and larger social patterns.

Site

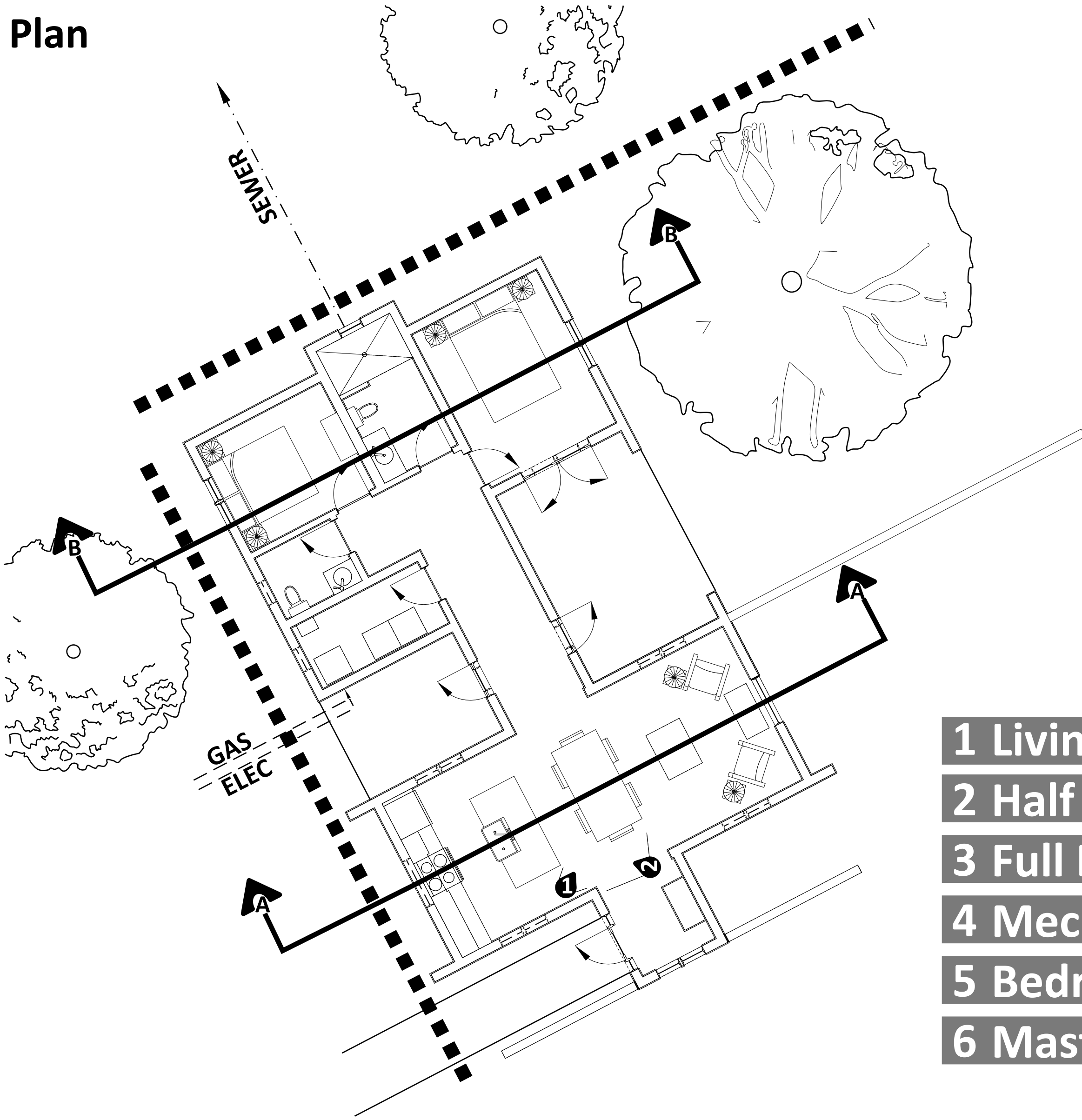
Fargo N.Dak

The site is symbolic model of a 22000 square foot lot. Modeling and project goals need to be generalized site to create unbiased results. Performace modeling will use geographic data related to the location.

See Page 56 and 57 for site data.



Plan



1 Living-Kitchen	423.6
2 Half Bath	40
3 Full Bath	78.3
4 Mechanical	63.9
5 Bedroom One	107.145
6 Master Bedroom	156.5
Total Final Usable	**1130.6**

Spaces

The home has a total of 1130.5 usable square feet, with a total construction cost of 67000 dollars. The home is all on one level, and is wheel chair ready. Although the home is smaller than the maximum allowable square footage by budget it has the functionality that is required at a lower cost. The smaller footprint also allows for the conservation of materials. This allows for better finishes and construction, resulting in longer product life.

The main living and kitchen are 423.6 square feet. This space offers a comfort from its quaintness and size. The space is centered around large dining table. This is a representational of the heart of the home and a gathering place for family and friends. The kitchen has appropriate storage for a family of three. The large kitchen island provides ease of serving. The full bath is 78.3 square feet. The space is ADA ready and could easily be converted to full wheel chair use.

The full bathroom has a single sink and standard toilet. The focal point of the bathroom is the large roll in shower which fills the entire north wall of the bathroom. The space is optimized by placing all fixtures on a single wall.

The half bath is 40.5 square feet. The space is wheel chair ready, accounting for needed swing radiuses. The space is at the minimum allowable square footage needed.

The smaller bedroom is 107.1 square feet, which is larger than the minimum set by the International Residential Building code at 70 square feet. The focal point of the bedroom is the cluster of windows on the western wall. These windows offer views of the setting sun and serves as a point of egress during emergency. The space is designed for minimal furnishing, with the use of built in storage as much as possible. The combination of space attributes offer as an optimal layout.

The mechanical room is 78.3 square feet. This space houses the environmental equipment. The layout also allows the addition of a laundry area. The location of the mechanical room allow for the hiding of services entering the home. The space is located as central as possible in the home. The space includes a gas fired instant water heater. This was done to conserve space and energy.

The master bedroom is 156.4 square feet. The focal point of the space is the French doors on the south wall entering out into a small courtyard. This feature, along with a cluster of windows on the east wall provide as a means of egress in case of emergency. The windows on the eastern wall also allow the bringing in of morning light. Furnishings in the bedroom are held at a minimum. The courtyard also would allow the addition of another bedroom in its place.

Construction

Wall construction used in the home is a modified staggered stud stick frame. The wall uses nominal size two by fours for studding material; which are spaced at twelve inch on center for exterior side, and twenty-four inches on interior side. The wall also employs boxed corners for ease of union and strength. The base, top, and crown plates, are two by eights, number two, SPF, with an actual width of 7.25 inches. This type of farming poses advantages over traditional two by four or two by six construction. The use of wider plates allows a wall that is deeper. This allows the use of thicker insulation materials, resulting in a higher final R value than is available with traditional stud wall construction.

The use of a staggered stud configuration creates a thermal break, increasing the interior comfort of the completed wall. The wall includes the use of furring strips on the interior portion of the construction. This adds lateral bracing the wall and creates a thermal and acoustical break within the wall. The furring strips are spaced to support five by ten sheets of 5/8th thick drywall. The insulation specified in the home is 7.25 inch thick Rockwool with a maximum R value of R30. Rockwool is a highly fire resistant material produced from industrial waste. The cost of the finished wall in comparable to a traditional two by six wall construction. The exterior sheathing is 7/16th oriented strand board (OSB). The use 7/16th OSB allows for runs of up to twelve feet without a need for a break in sheeting. This greatly improves the overall strength of the wall, and lowers the construction and time and cost. This should also minimize waste. The exterior vapor barrier is thirty pound impregnated felt paper. This was found to be appropriate for use, and lesser cost than other barrier types. The interior wall uses 5/8ths drywall in five by ten sheets. With the use of a ten foot stud, this optimizes the layout by decreasing the number of individual sheets of drywall need. This also minimizes the number of joints to finish or crack. Three and a half inch base molding is used to finish the interior wall. The exterior cladding is insulated panels with a concrete facing, dyed white. This increases the R value and decreases the need for exterior maintenance.

The wall construction also includes inch and a half non metallic tubing, at eighteen inches, forty-eight inches, and eight feet. This eases the possible future expansion of either electrical or communications used in the home. This also decreases the chance of screws or nails piercing wiring while hanging drywall or pictures. The finial R Value for the completed construction is a R46, which is over the minimum requirements for North Dakota, with standard as R20.

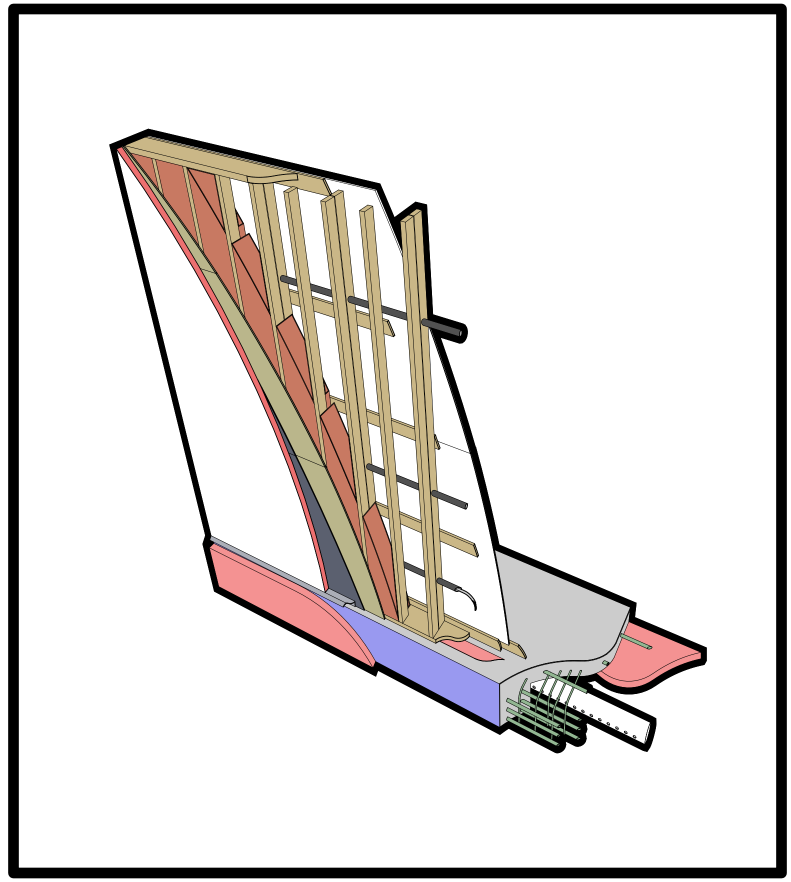
The roof framing in the home uses web truss construction. This was found to cost more than using I trusses, but offers a higher load capacity and space for mechanical and environmental services.

The foundation is a floating slab with bond beam edge. The slab is six inches thick and the beam is a twelve by eight. This was found to be the lowest cost option. Number eight rebar is placed every twelve inches in a grid pattern, in the lower third of the slab. The rebar is tied back to the edge bond beam every six inches. All rebar is urethane coated. Two inch foam insulation is placed along the parameter and underneath the slab to prevent thermal bridging and add to the comfort of the occupants.

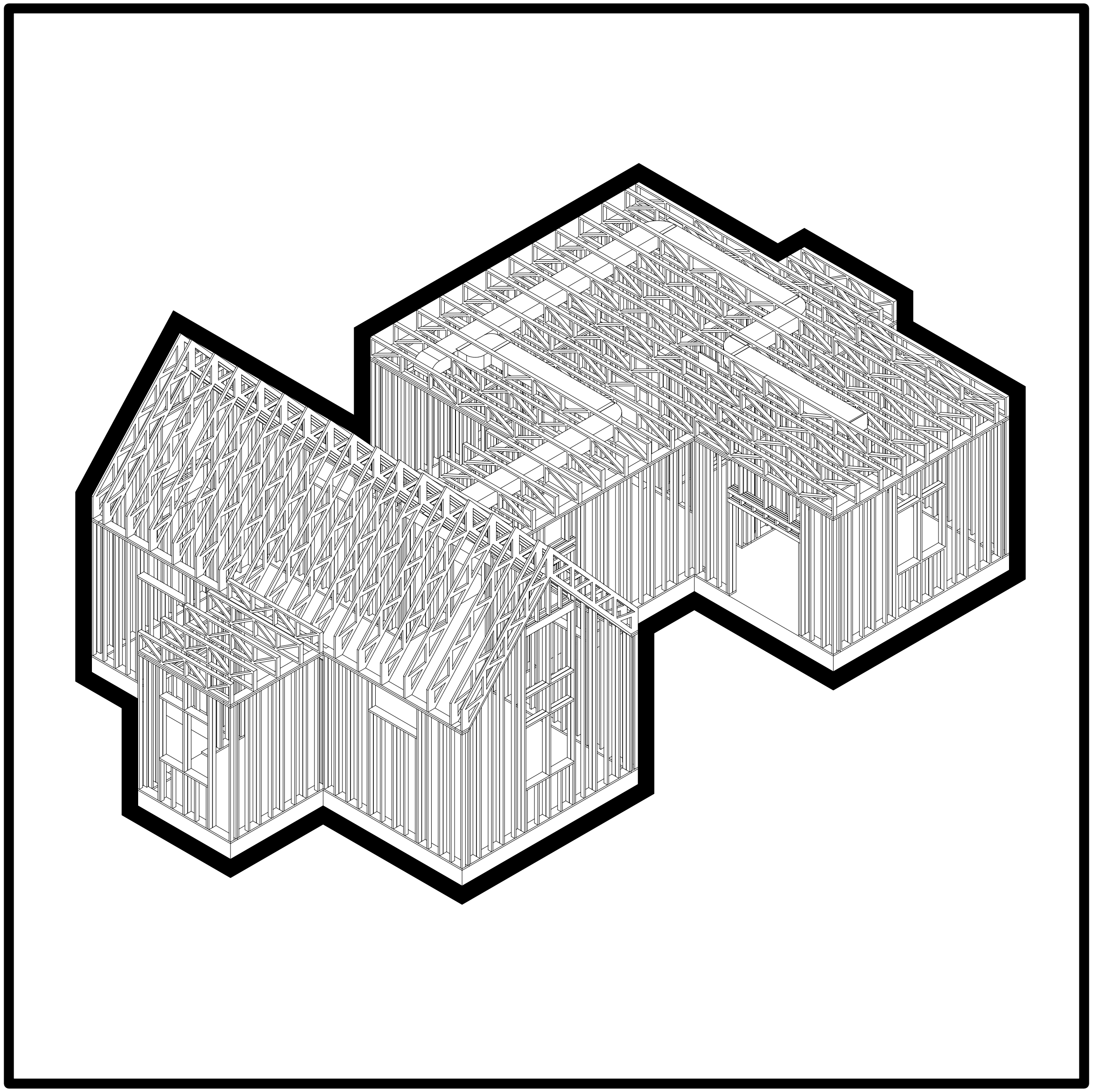
The home has a force hot air gas furnace rated at 750000 BTUs and an air conditioner rated at 500000 BTUs. The system uses twelve by eighteen steel ducts, with eight inch round registers in all rooms except the main living area. The register for the main living area is twelve by eighteen. The system return is done by a vent in mechanical room door. This system is larger than is needed by the total square footage of the home. This makes it possible to expand the home without a need to buy new environmental equipment.

Plumbing in the home follows standard practices for waste and drain. Water supply lines are PEX with a hot and cold supply manifold in the Mechanical room . This greatly reduces the rough in time and cost. This method also minimizes the chance of leaking or bursting pipes in inaccessible areas. The sewer can be either connected to a city waste line, or septic system. The addition of a septic system would cost 35000 dollars more. The unique framing of the home incorporates wet walls between the mechanical room and half bath, and smaller bedroom and master bath. This was done to house plumbing and vents. This also allows for an acoustic break that should isolate unwanted noise.

The home has a 350 amp electrical service. This is above want is needed for home size, but allows for future expansion of the home without a need to update or add a new service. All wiring in the home is 10/3 machine tool wire (MTW). This wire is of a higher quality than standard romex, but offers the ability for tight bend radiuses and a continual flex rating. All plugs in the home are arc fault type with ground faults in kitchen and bathrooms. Crows foot services are placed in both the kitchen for oven and in mechanical for clothes dryer. Lighting is done by standard sixty watt fixtures in all rooms, with under cabinet lighting A in the kitchen.

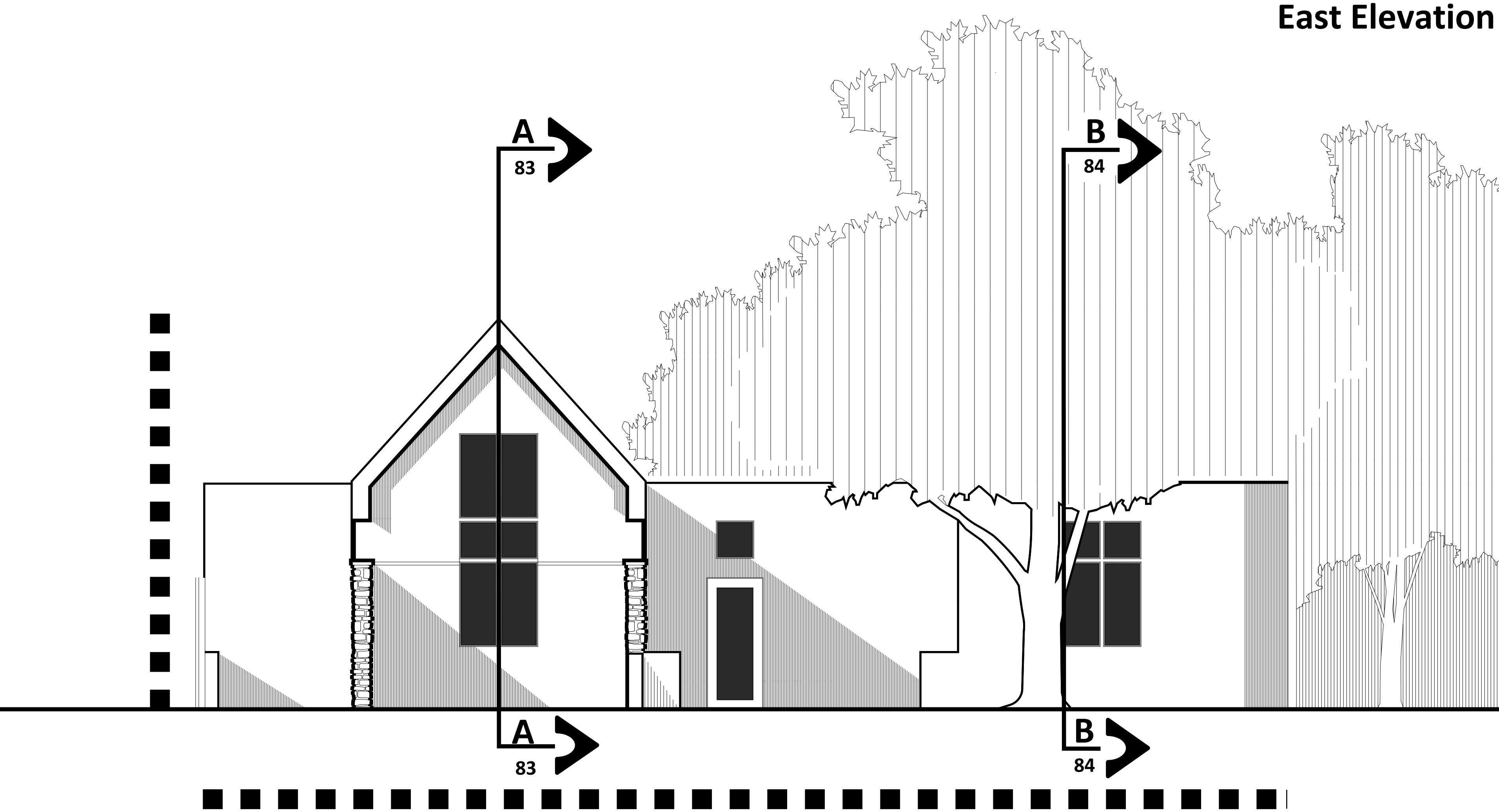


Wall Construction Info Graphic



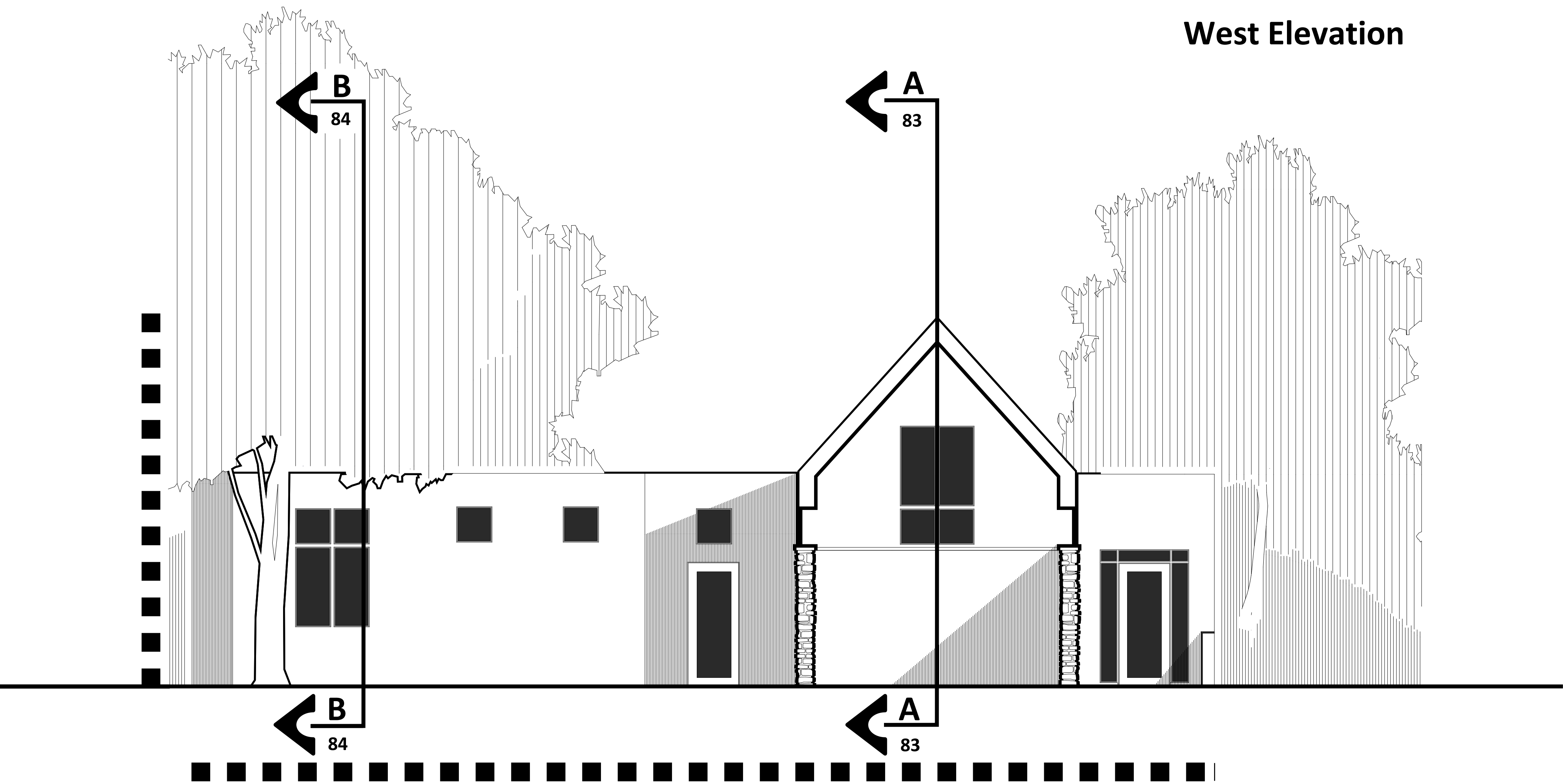
Structure

East Elevation

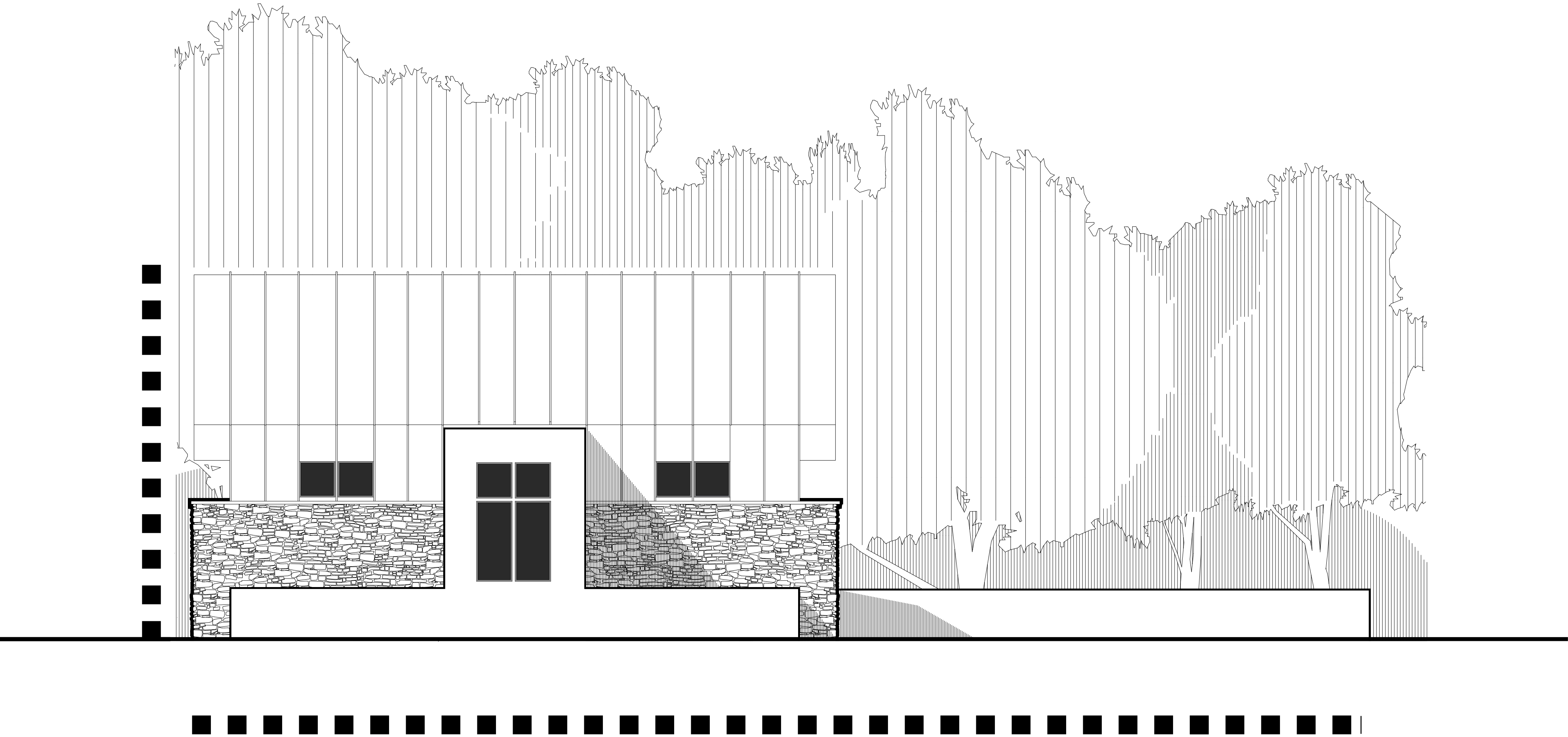


North Elevation

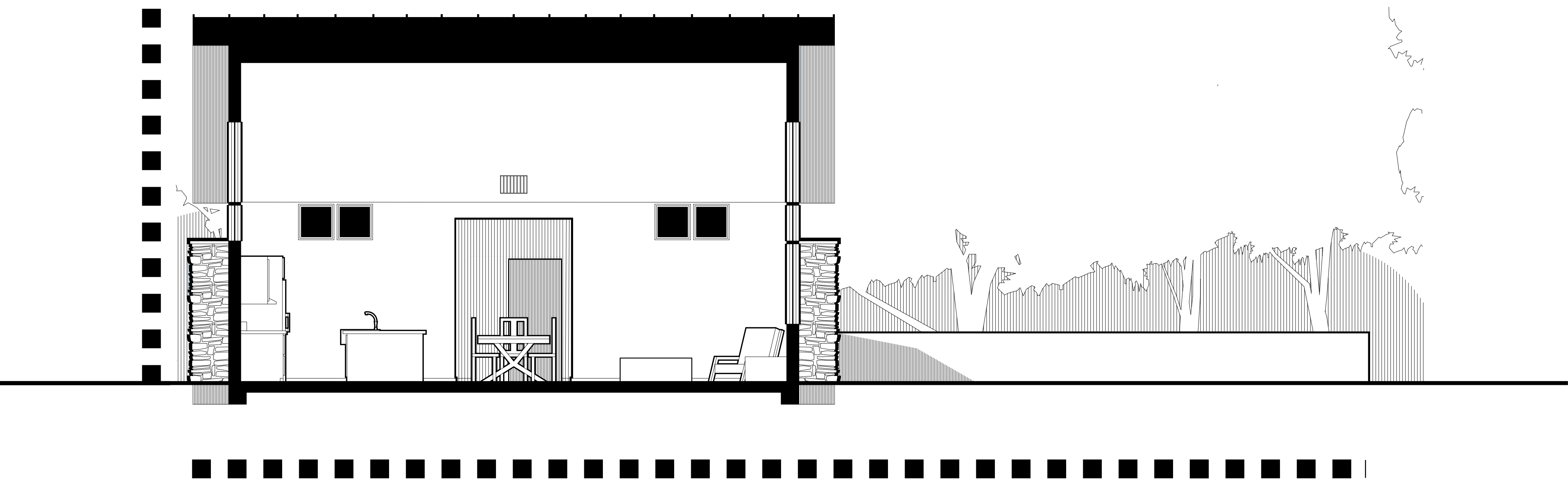
West Elevation



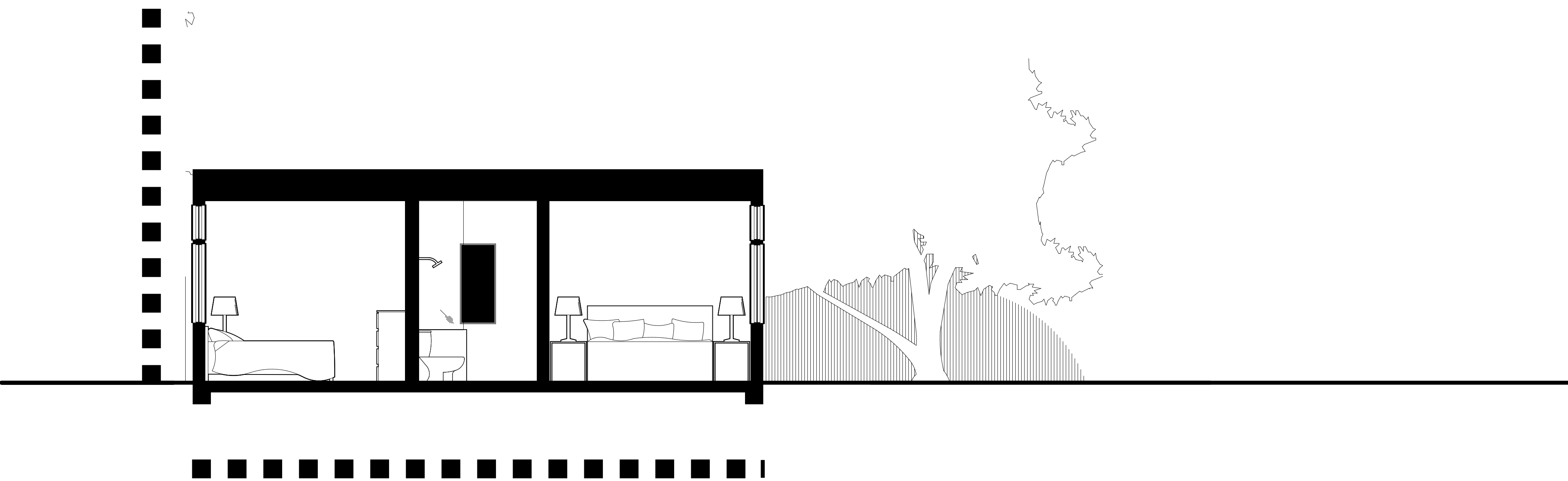
South Elevation



A Section



B Section



Looking North


4·2018

1

PG 74

2

PG74

Studio Experience

Arch 271-Fall 2012:Darryl Booker
Projects:
Tea House, Fargo ND
Boat House, Minneapolis Mn

Arch 272-Spring 2013: Rhet Fiskness
Projects:
Dance Studio, Moorhead Minnesota
Streetscape Design, Fargo, North Dakota
Culinary School, Kyoto, Japan

Arch 371-Fall 2013: Steve Martins
Projects:
Wildlife Center, Northern Minnesota
Retirement Community, Canada

Arch 372-Spring 2014: David Crutchfeld
Projects:
Star Institute, Fargo, North Dakota
Learning Tree School, Chicago, Illinois

Arch 373-Summer 2014: Bakr Aly Ahmed
Project:
Steel Competition, Boarder Crossing, Minnesota

Arch 471: Don Faulkner
Projects:
Highrise, San Francisco, CA

Arch 472: Don Faulkner
Project:
401 Development, Fargo, ND
City Design, Alberta, Canada

Arch 771:Ganapathy Mahalingam
Project:
Advanced Research Studio

About the Author

Christopher was raised in rural North Dakota, in a farming community with a population of less than 2000. He practices in residential construction as a master carpenter, with an education in architecture and engineering. When not pursing his masters in architecture, he works on residential, agricultural, and industrial projects in both Minnesota and North Dakota. His areas of study are in residential construction, technical theatre, and equipment automation.

Address:
592 166th SE
Hillsboro, North Dakota
58045-9262

References

Radford, Gero (1988). *Design by Optimization, in Architecture, Building, and Construction*. Van Nostrand Reinhold.

Robert J. Gordon(2016). *The Rise and Fall of American Growth; The U.S. Standard of Living Since the Civil War.* United Kingdom: Princeton University Press.

Kenneth Boulding(1966).*The Economics of the Coming Spaceship Earth*. In H. Jarrett (ed.) 1966. Environmental

Thomas Kuhn (1962). *The Structure of Scientific Revolutions*. Chicago: University of Chicago Press.

Le Corbusier(1931).*Towards a New Architecture*. London: John Rodker

Frank Lloyd Wright (1941).*Frank Lloyd Wright on Architecture: Selected Writings, 1894-1940.* New York, New York:Duell, Sloan and Pearce.

Frank Lloyd Wright (1943).*Frank Lloyd Wright an Autobiography*. New York, New York:Duell, Sloan and Pearce.

Site: https://www.bea.gov Accessed September 2017
Site: https://www.census.gov Accessed September 2017