Negotiating the Slope:

Prefabricated hillside dwellings meet Nordic influence

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1 Introduction

1.1. Preface

In Wellington we are faced with the difficult task of building on our undulating topography. It does however offer inhabitants stunning vistas and to architects the rare opportunity to explore new ways of building, generating distinctive typologies.

However, it is questionable whether a bespoke construction method is the most appropriate means for building houses on hillsides in present times. Prefabrication has been a prevalent housing construction method in Scandinavia and for many years and offers a number of advantages, particularly to difficult sites (Smith 255). It is emerging as an option for housing in New Zealand but faces significant problems when confronted with sloped topography (Rouillard 137).

The prefabrication movement has become synonymous with the stylistic outcome of modernist detached dwellings, and while this marriage may be an outgrowth of intention rather than a technical requirement, challenging the rectilinear is relatively unheard of (Smith 251). The stylistic concerns embedded by fanciers of 50's modernism are inherent to the representation of manufactured housing (Smith 251). For prefabrication to become popular in present day society misconceptions regarding stylistic limitations must be resolved.

Residential architecture has the potential to shape our architectural identity more significantly than civic buildings. I propose this because we form a closer relationship to 'home,' and as a typology they cover a significant proportion of our landscape. To understand how to form an architectural response in the context of Wellington, I looked to contemporary Norwegian architecture which demonstrates contextualising architecture to the landscape. The stylistic character of Norwegian design, and parallels which made their principles applicable to New Zealand, were additional incentives for this focus.

This thesis is broken into four parts; background research, design explorations, design discussions and conclusion. In background research, I establish parameters for constructing houses on hill sites. Technical limitations are presented and a range of hillside typologies are identified. Prefabricated systems internationally offered are documented accompanied by the technologies available specifically in New Zealand. The design exploration section illustrates two designs which explore how a hillside typology can be augmented with a prefabricated system. Each is assessed in relation to response to topography and adaptation of Norwegian ideologies. The design discussion revolves around a hillside development of five residential structures and their interconnectivity. Leading into the discussion is a detailed analysis of the prefabrication system implemented, and the modifications to that system which were tested through design. Here, the construction sequence is mapped. This is followed by an architectural discussion on site, access, planning and materials. The conclusions drawn in the final section tie together all these elements.

1.2. Problem Statement

Figure 1: Typical representation of prefabricated housing - Rocio Romero

"Industrialization needs no specific site or region. It begins with the ideal lot: flat, linear, clear-cut, firm, uniform, universal. Since nothing is less likely to be found than the ideal, one has to wonder if it wasn't the very difficulty of the site that demanded the invention of a sophisticated technology. At the same time one must ask whether the universal applicability of industrialised construction has been proven in the most difficult situations."

- Rouillard 133

As introduced, prefabricated housing is primarily dominated by systems which appear suited exclusively to flat sites, particularly if they are modular because they do not adapt to the challenges set by sloped terrain. "The adaptability of a construction system to the different site conditions is dependent upon its flexibility" (Rouillard 145). Prefabrication needs to offer customized design solutions if it is to respond to the nature of the inclined plane.

Often the transition from a prefab house on a flat site to one sited on a hill is the addition of stilts, raising the 'shipping container' like form above the incline and negating the site (Rouillard 155). The architecture is thus completely separated from the site and the context of the slope becomes irrelevant. An even more common scenario is to scar the site through excavation to create a flat platform on which to build (155). This practice of carving and reshaping the land removes the very nature which characterised it to begin with. Leveling or terracing the hill does not use architecture to solve the problem of site. It is a means of imposing a flat site design solution on sloped terrain.

The question of how we can formulate a solution for housing which is an architectural response to New Zealand's identity and conditions is challenging to answer. Historically we have inherited an architectural language from Britain, yet this is arguably not the most appropriate response to the specific conditions, environment and identity of Wellington.

This leads into the problem of contextualisation, or in other words, how we can link contemporary residential architecture to New Zealand's identity and the specific conditions we are faced with.

1.3. Research Aim

This research aims to illustrate the potential for prefabricated construction methods for hillside residential development. The thesis also intends to establish links to global architectural trends as a means of demonstrating parallel principles of contextualisation in the designs presented.

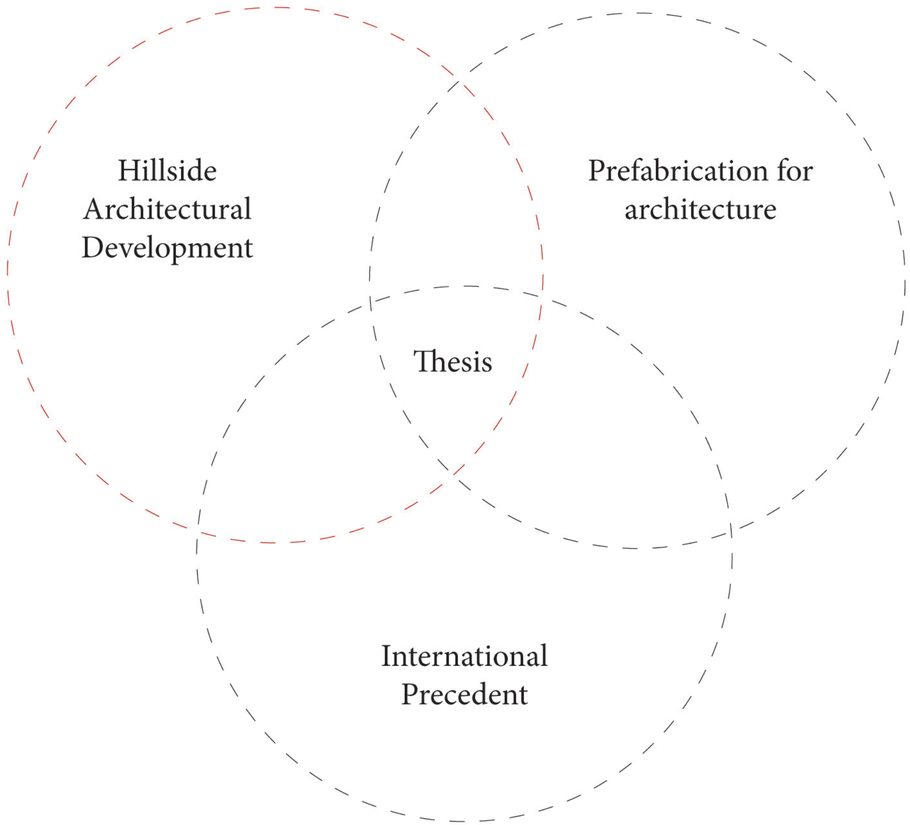


Figure 2: Venn diagram illustrating research field - Author's own

1.4. Research Question

1. How can prefabricated construction systems be adapted for acute angled sites?
2. How can limitations and technical restrictions inherent to hill sites be alleviated through architectural design moves?
3. What aesthetic considerations need to be considered for the local context of New Zealand?

1.5. Scope of Study

The needs and desires of clients within the housing market are vast, thus parameters were established to limit the scope of research. A particular circumstance was determined, that being, the houses would be intended for double–income couples without children, wanting a home on a hillside property in Wellington which reflected the philosophy of 'genius loci' or spirit of place.

This thesis questions how Norwegian architects respond to their context, and how we in turn can respond to ours. By establishing this condition, an aesthetic scope is determined. I look at how form and materials are used by Norwegian designers to relate architecture to the landscape. This is used to inform how one can look at the landscape of Wellington along with the particular contextual conditions, such as high winds, to respond with architectural design moves.

The scope is narrowed further in the thesis, which is explored by a matrix representing the relation to topography, materials and environments.

1.6. Limitations

Technical restraints specific to hill side construction, along with the design limitations which prefabricated systems inflict, narrow the field of research. As is the case with all architectural design, the possible outcomes are vast. However, through this research the knowledge and skills of hillside design and the utilisation of prefabrication methods will be acquired.

Through the course of the literature review, a number of key precedents arose as most suitable. These included, but were not limited to, Hill House by Johnston Marklee & Associates, construction solutions by KLH, and Cabin Vardehaugen by Fantastic Norway. They provide insight because they represent the most appropriate typology, prefabrication system and contextual response for the hill site presented in the developed design.

Additionally, Pamela Bell and Mark Southcombe state that prefabrication can be broadly assessed as having 5 main typologies which are component, panel, module, hybrid and complete building (Bell, Southcombe 64). After analysing each, it was determined hybrid was the most appropriate for a hill side house of this scale. Hybrid represents the combination of a panel system with a modular system, offering a high degree of customisation while maintaining schedule saving benefits. The component prefab typology was dismissed as it does not adequately challenge the current mainstream method for housing construction; while modular was dismissed for the rigidity of limitations in form and hill site access restrictions. Through this analysis the field of research was limited.

1.7. Methodology

This thesis alternated between Peter Downton's concepts of research for design and research through design (Downton 17, 123). Thus, the collection of research material was conducted at several phases throughout the course of design iterations to test viability of the design solutions. Downton acknowledges that to establish a method within design research is immediately "awkward" "as a secondary designer is unlikely to get the same result" (Downton 12). Naturally the reason for employing a method in science is to obtain the same outcome if the conditions are held identical or to be informed as to what caused a different outcome (12). This thesis acknowledges this discipline does not fall within the kinds of strictures imposed by adherence to methods concerned with replicating prior outcomes. Methodology is defined as meta-method; therefore, the following paragraphs illustrate an overview of the thesis instead of a detailed method (12).

Due to the parameters set, two distinct topics exist in this research, namely, the utilisation of prefabrication systems for hillside construction and the re-appropriation of philosophies embedded in Norwegian architecture. These two topics constantly interact with one another throughout the research. The design process is evaluated by the degree of success Norwegian ideologies are instigated and measured against the analysis of technical restraints for both prefabrication and hill side sites. Case study analysis provides the basis for the analytical discussion.

To form the foundation of this research, material on prefabricated technologies and hillside architecture and construction were investigated and collected at several critical stages throughout the design process. Norwegian architecture was examined in the context of architectural response to landscape and material articulation. The design studies and iterations tested particular typologies which are illustrated in the hill side typologies matrix.

2 Background Research

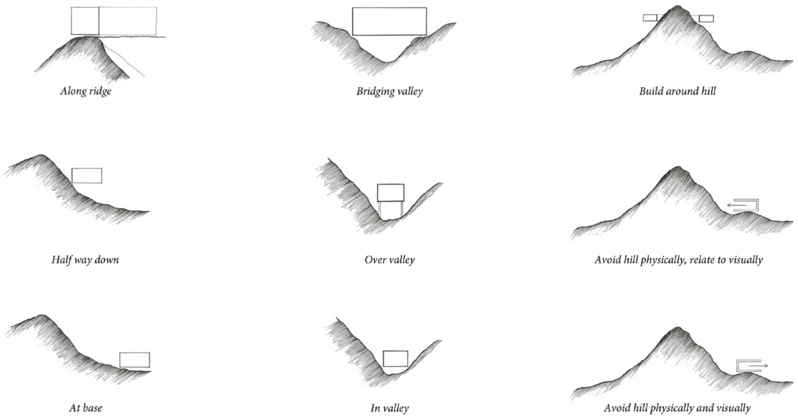
2.1. Hill sites: the topographical canvas

Figure 3: Hill housing Wellington - Jenelopy

Design Typologies

In Wellington, the hillsides which constrain us also cause distinctive typologies to emerge unique from flat site housing design. Dominique Roulillard, author of *Building the Slope: hillside houses 1920-1960,* conducted a study of the design principles and techniques used by architects to build houses on hillsides in California. Concepts of case studies are diagrammed in the text to draw out the principles of designs. Each architect is acknowledged as giving rise to a series "as if to exhaust the possibilities of this new language" (Roulillard ix). Frank Lloyd Wright "used idioms of geology" while R.M. Schindler "worked with a more abstract language of imagery and theory, the movement of solids over inclined planes" (Roulillard ix).

In order to comprehend the scope of opportunity, I began hand drawing from the text to clarify the concepts and formulate them into two single comprehensible diagrams to establish relationships between them. There is a focus upon configurations and how to reconcile an inclined plane, which tends towards imbalance, with a more or less "parallelpiped volume" or say, rectilinear form (Roulillard 13). In this text, the question of form is studied independently of an ideological construction. The first diagram (figure 6) includes my sketches of different hillside siting possibilities as proposed by a Professor at the University of Arizona (15). These analytical sketches are made independently of the design process and are established in a totally abstract manner. Thus, with an absence of context, they prohibit real analysis. It is argued by Roulillard that these do not present real situations and "to arrive at a useful configuration one must have a real solution," because the house itself



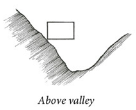


Figure 4: Mapping relationships between architectural form and slope - Author's own

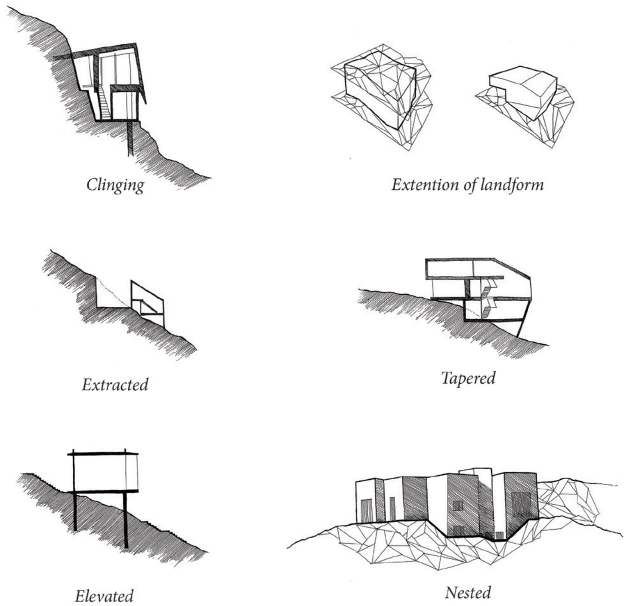
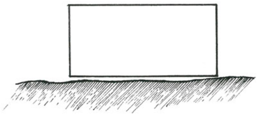


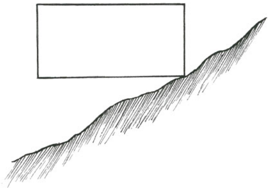
Figure 5: Hill housing typologies - Author's own

cannot in every case be reduced to a simple rectangle (Roulillard 13). While I agree a rule book cannot be created to completely resolve an architectural solution for any hillside site, there are certainly ways to argue why one system is more generally suitable in the context of Wellington when we measure it against cost, construction difficulty, site type, soils and geology and material influences.

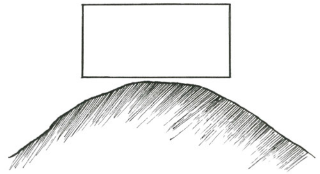
To bring the typologies of hillside configurations closer to a design discussion, or as Roulillard would say, a "real" solution rather than abstract idea; I decided to conduct my own diagrammatic analysis based upon contemporary hillside architecture (figure 7). The text *Homes on Distinctive Land* contains a collection of plans and photographs of architecturally designed houses around the world, many of which are sited on hillsides. These present an array of distinct solutions for sloped sites which could be analysed and compared.



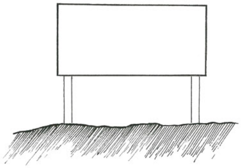
Building on ground



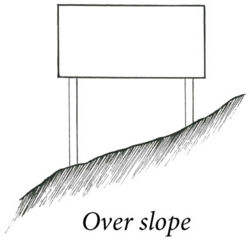
On slope



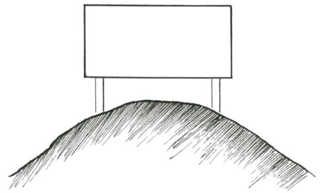
On hill



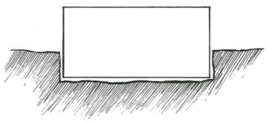
Over ground



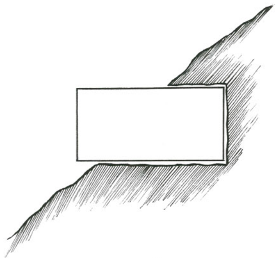
Over slope



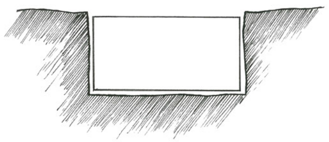
Over hill



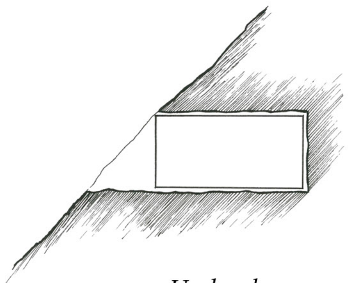
In ground



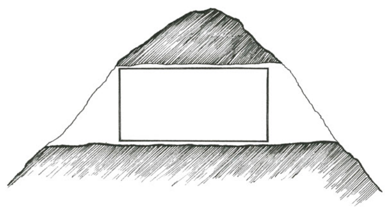
In slope



Under ground



Under slope



Under hill

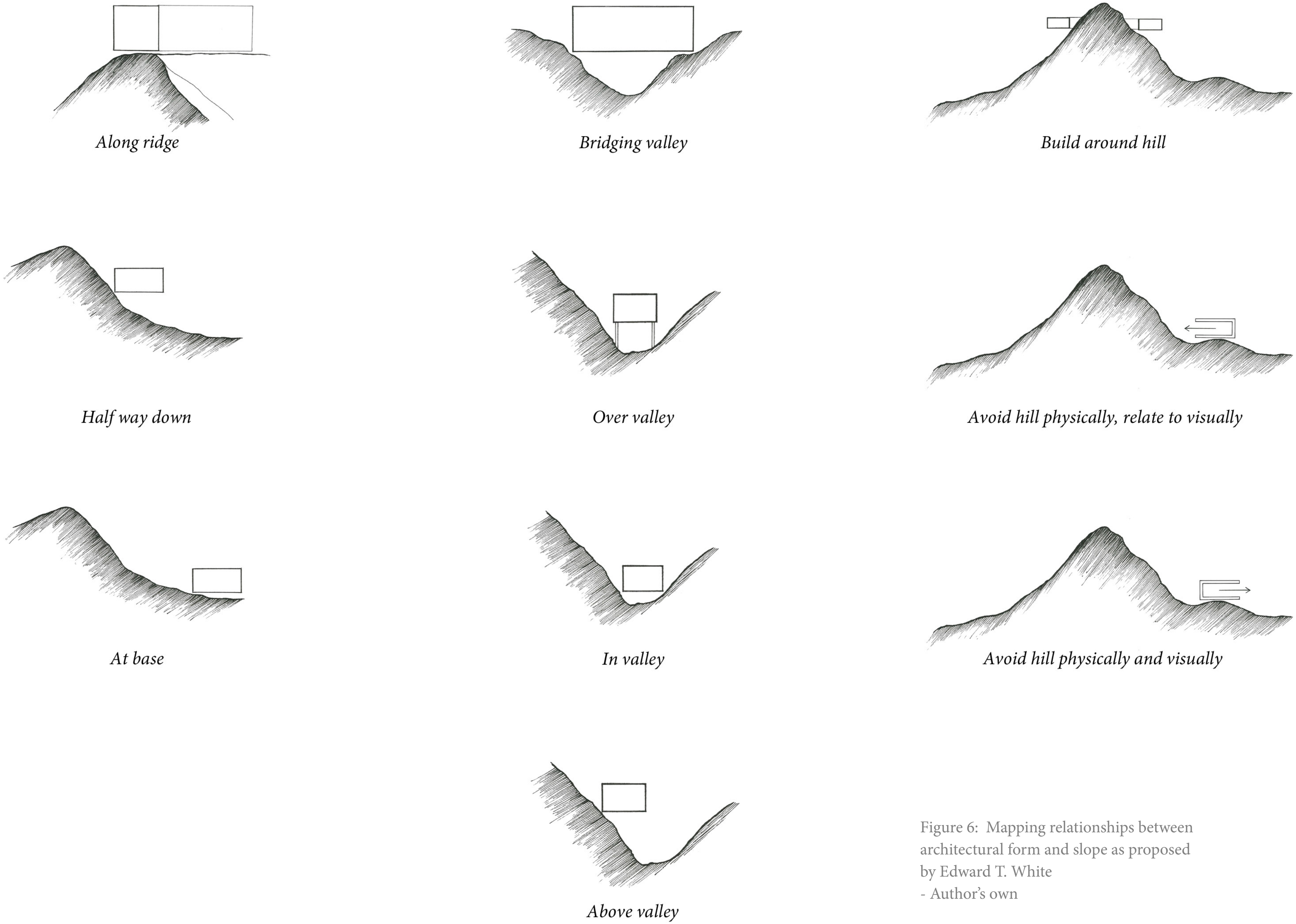
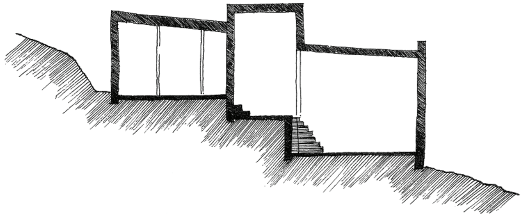
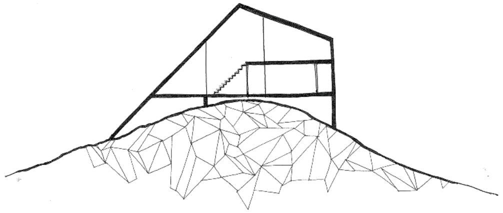


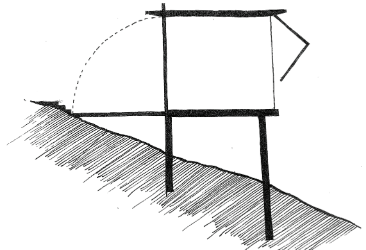
Figure 6: Mapping relationships between architectural form and slope as proposed by Edward T. White
- Author's own



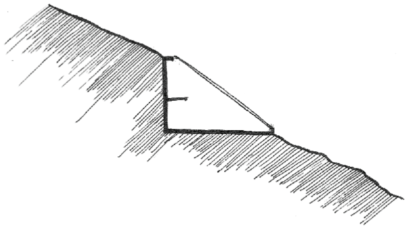
Split level



Balancing



Elevated



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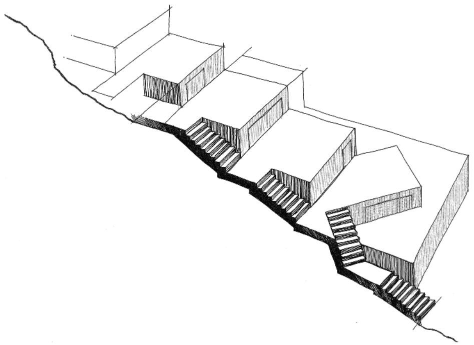
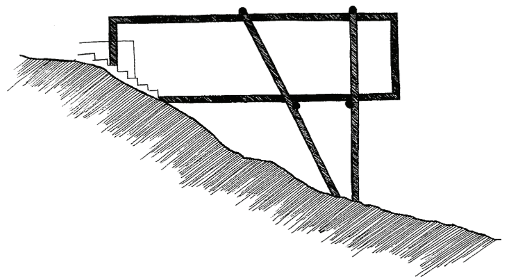
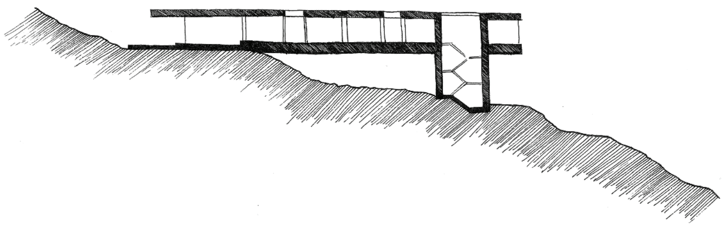


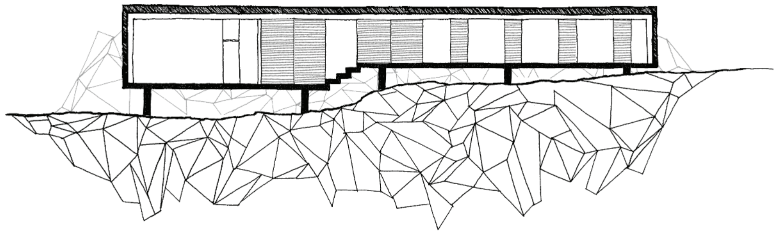
Stepped



Cantilevered

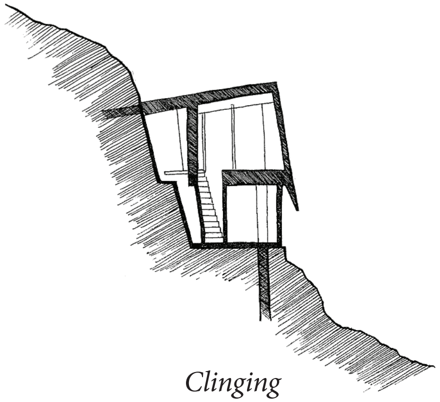


Bridging

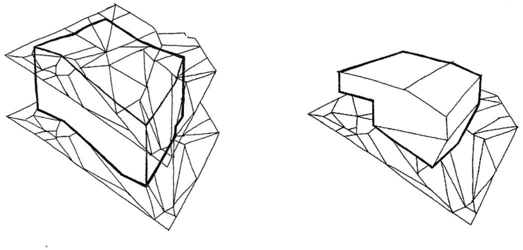


Traversing

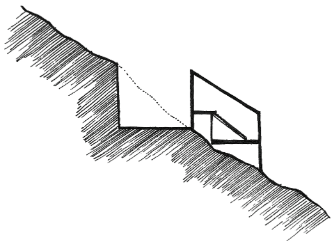
Hill Typology Matrix



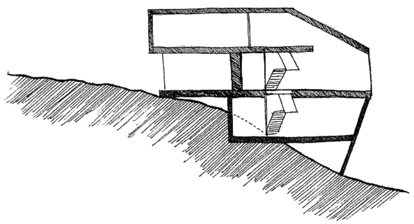
Clinging



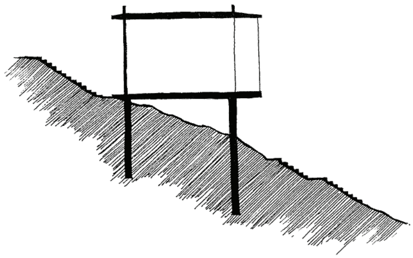
Extention of landform



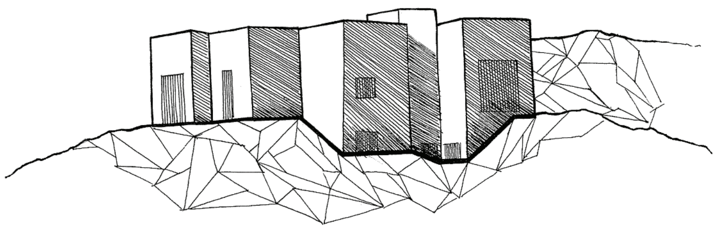
Extracted



Tapered

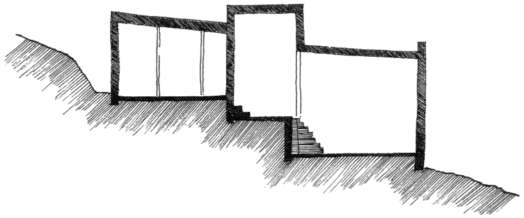


Elevated



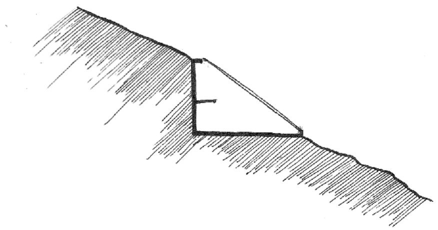
Nested

Figure 7 : Hill housing typologies - Author's own



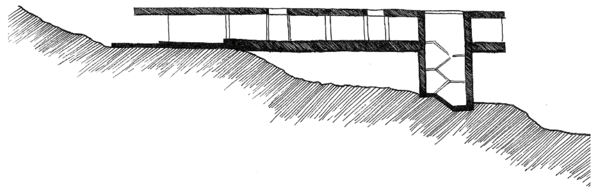
Split level

- Common typology for hill housing
- Experience of living on incline evident in interior with offset levels
- Progression down or up hillside can be incorporated into space planning such as progression from public space to private
- Opportunity for double height ceilings on lower levels
- Central core can feature as nucleus of house when there are three levels, as it does in this sketch
- Adaptability to acute slopes problematic
- Architectural response to context of terrain, medium
- Requires some level of grading, land must be terraced
- Modular construction possible if customised, and is dependent upon access to site as a crane with a high loading capacity would be required
- Panelised construction possible but may meet challenges at foundation level
- Buildings in front of house may conceal view
- Opportunity to focus outlook on landscaping and terrain either side of house, but must consider privacy issues



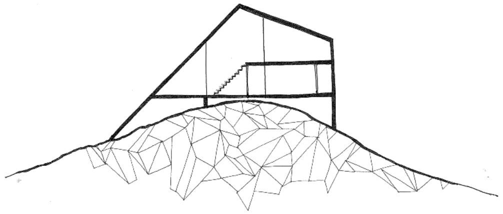
Inserted

- Level of excavation high, site preparation would be expensive and require major retaining walls
- This typology is sometimes implemented for passive housing on hill sites as earth is an excellent insulator
- Interior experience may induce feeling of being in hill but the slope is not seen from the outlook, nor is it reflected in level changes within the house
- Architectural response to context of terrain [solving the problem of sloped site] -minimal
- Prefabrication is unlikely to be commonly instigated in this building type as retaining walls form the structure and these would likely be executed in-situ
- Degree of construction difficulty and cost – high



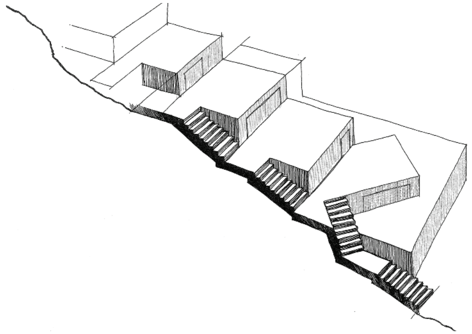
Bridging

- Unusual typology, architecturally intriguing
- Accentuates the landform and emphasizes dips and variations in terrain
- Void under the bridge creates a focal point, highlighting the organic line of terrain juxtaposed against the very linear lines which outline the building
- Minimises scarring of the land as there is not extensive ground works
- No requirement for retaining walls
- Interior program appears to be a linear progression to 'look out' point at the end of the building which extends out towards view
- No experience of living on the incline from within the building. There is no level change in program
- The relationship to the landscape is more evident from an exterior prospective, not particularly evident from the interior
- Prefabrication is feasible, prefabricated structural steel framing for example



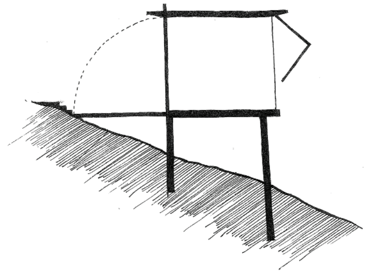
Balancing

- Leaves the landscape relatively untouched
- Very exposed siting, would have to be heavily engineered to resist high wind forces
- Prefabrication is limited by site access
- This is a particular terrain situation and not a site situation commonly used for hillside construction; therefore, it is not an ideal typology to base the thesis upon when wishing to look at more generic hill site construction



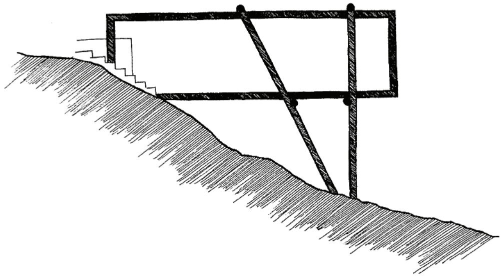
Stepped

- The architecture follows the land form
- From an interior point of view, perhaps this typology accentuates the experience of living on a hill side to the greatest degree as each room is located at a different level on the hill. There would constantly be this progression of moving up the hill or down the hill within the home.
- There are limited views as this is a low lying typology
- Likewise on the exterior of the building, the roofs create multiple outdoor living terraces
- Opportunity for customised or adaptive modular construction as each module may be small enough for transportation

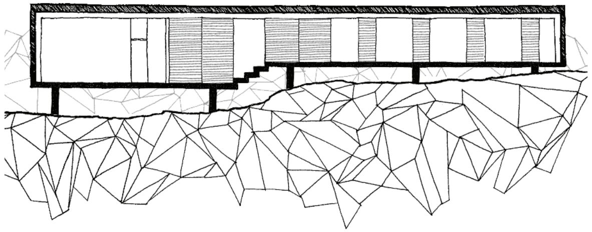


Elevated

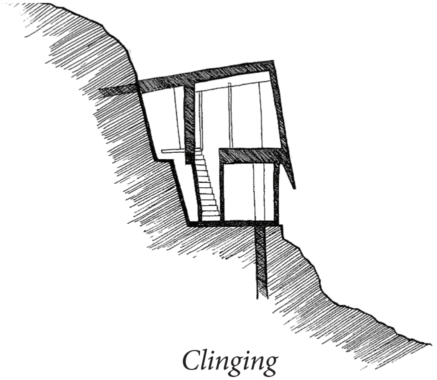
- Classic pole house typology, careful design regarding appearance of poles must be considered, e.g. large poles but few in number, or more poles which are more slender. The foundation is quite heavily dependent on soil type and structural engineer recommendations for that soil type.
- A distinct element separated from landscape. Perhaps does not express ideas of contextualisation well
- Interior relationship with incline is not clearly evident
- Prefabrication a possibility, again must consider site accessibility



Cantilevered



Traversing

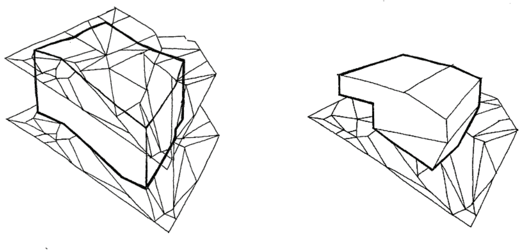


Clinging

- This typology may appear dramatic, but the only deviation of design from flat site construction is the addition of poles raising the rectilinear form above the slope. The form is universal and does not engage with the terrain but rather is quite divorced from it. The typology does not deviate greatly from flat site typologies and does not challenge the rectilinear nature of prefabrication to date
- Grading is unnecessary
- Prefabrication may be modular or panelised and is dependent upon site access
- This type of construction is not recommended for houses on steep slopes or slopes which are more inclined to be a landslide risk (Sew 3)

- This typology angles across the hillside and steps down to follow the land
- Good for very steep or potentially unstable sites as the foundation differential on the slope is minimised
- Some experience of living on the incline evident in planning
- Opportunity to divide public area from private area over two levels
- High ceiling in living space
- Appears suited to prefab structural panels or prefab structural steel frames

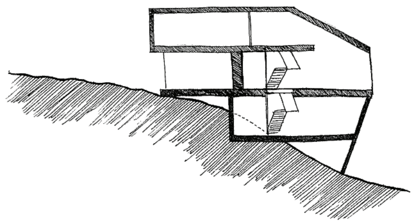
- This typology presents a solution for very steep sites, however, grading and major retaining walls required



Extention of landform

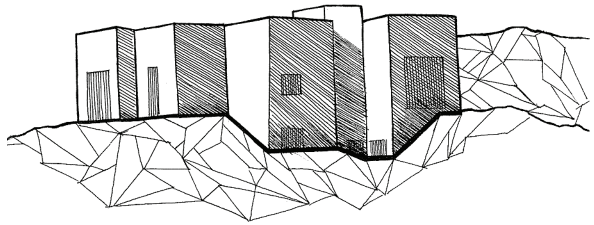
» Panelised or component prefab most likely to be effective. Unlikely to break into modular components.

» This design translates the landscape to architectural form rather directly. The result is not a mimicry of the terrain, but rather a simplified/abstracted interpretation of it. It is a good example of contextualizing architecture, generating a design unique to the land which it is upon. Further design moves add tapering to the sides of the building, remnant of the faceted digital topography.



Tapered

» Interesting non-linear form
» Roof form mirrors angle of slope
» Split level can be implemented
» Grading minimal
» 'Skirt' conceals void under structure



Nested

» Creates negotiation between land and building as land is not completely level
» Comparable to geological thrust [Schindler]

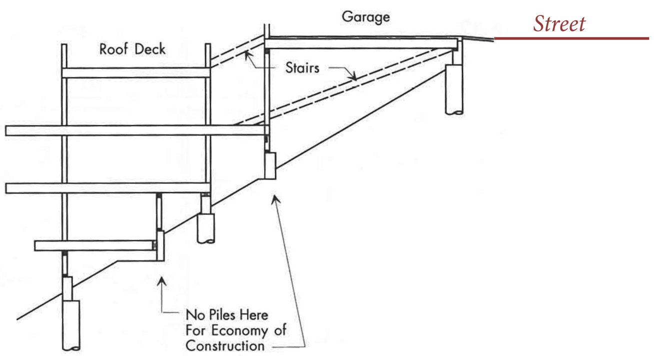


Figure 8: The downhill building - Arthur Levin

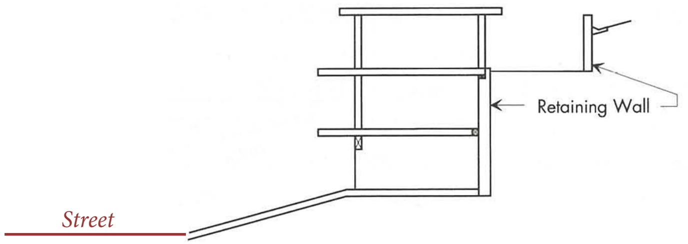


Figure 9: The uphill building - Arthur Levin

Technical Restraints

Concurrently to typological considerations, one must be constantly assessing the many technological challenges hillside construction inflicts upon design. (Downton). Arthur Levin's text *Hillside Building: Design and construction* is a comprehensive study of the pragmatics involved in hillside construction as opposed to theoretical architectural discussions. To place the author in context, Levin is an architect who specialises in hillside housing in California. The first four chapters of the text deal with factors generic to hillside development and the remainder is organised into particular site configurations, that is, uphill, downhill or flat.

Levin's established three scenarios of "site configuration" are highly influential to architectural typology, spatial arrangement (plan typologies) and building placement. An uphill lot is one which is on the uphill side of the street; likewise, the downhill site is on the downhill side of the road. Flat sites refer to those which have undergone grading (cut and fill) to been made flat. These three scenarios require different approaches; however, as this thesis aims to focus upon the sloped site, flat hillside sites will be omitted as their construction does not differ greatly from standard flat site construction.

As mentioned, there are a number of factors which both uphill and downhill sites are subjected to. One of the main technical limitations is the soil and geology of the site. The soil and geology report has a significant influence upon the placement of the building, the foundation system and any site works. It is thus highly recommended a preliminary study of the soils and geology be carried out prior to purchase of the land to determine the stability of the slope. Landslides and rock falls are a very real hazard to hillside construction and, in general, the steeper the site the more potentially unstable it is.

I have endeavored to condense the entirety of the text into three pages and diagrams which will serve as a framework to refer to in subsequent research. Much of the structural engineering details have been omitted due to being beyond the scope of an architectural thesis.

1.0 SITE SELECTION

- View – value of land proportionate to quality of view
- Steepness of slope – if more than 45 degrees construction difficult, cut paths and high retaining walls required, costly
- Location/neighborhood
- Condition and width of street
- Availability of utilities [electricity, water, sewerage]
- Legal requirements / zoning requirements [WCC district plan, Resource management act, NZ building code]
- Soil and Geology [Preliminary study prior to purchase of site – visual inspection, examination of all available documentation, underground exploration]
- Location of front property line
- Size and shape of lot
- Covenants, conditions and restrictions
- The downhill site [downhill side of street]
- The uphill site [uphill side of street]
- Flat or terraced site [cut / filled or both]

(Levin 1-10)

2.0 PROFESSIONAL TEAM

- Architect
  - On-site check
  - Legal check
  - Record check of utilities
  - Preliminary sketches
  - Engaging a surveyor
  - Coordinating with structural engineer
  - Coordinating with soils geology consultant
  - Coordinating the design
  - Obtaining permits
  - Contract administration
- Surveyor
- Soils-geology consultant
  - Preliminary assessment
  - Test boring
  - Recommendations
  - Soil testing and geologic planning
  - Preparing report
  - Testing man-made fill
- Structural engineer
  - Structural plans
  - Wind and seismic design
- Civil engineer [subdivisions, grading, streets, sewer or drainage facilities]
- Landscape architect

(Levin 11-18)

3.0 SURVEY AND TOPOGRAPHY

- Corner monuments
- Building location – before survey begins architect should show the surveyor the approximate building location
- Topographic plan [0.5m contours where building is to be placed]
- Footing and retaining wall locations
- Grade stakes and topography recheck [if site is to be graded new topography should be shown in plan]

(Levin 25-29)

∞ Piles, caissons, grade beams
- Friction piles or belled caissons supporting grade beams
- Pile determined by underlying, supporting soil. If it is a dense rock, a friction pile may not be possible. In most cases friction piles is the better choice
- Minimum use of caisson or piles – grade beams can span and cantilever farther than most engineers would expect

∞ Steepness of site – separation from cliff, retaining walls, geologist indication of stable cliff

∞ View – most important factor for determining location of building and placement of rooms. Where possible keep the walls parallel to the street along the contour lines (makes construction of foundation easier. For uphill site – to obtain view, raise height of each floor or step building up hill. Provide roof deck. Place dwelling or part of it up the hill separate from garage.

∞ Topography – Naturally the building should be placed where the slope is shallow unless the view or fill depth is unsatisfactory there.

∞ Soils and geology – The building should be placed where the grading and depth of fill are at a minimum (minimal foundation depth)

(Levin 43-102)

5.0 ARCHITECTURAL

∞ Garage access – The garage should be placed at the highest elevation of the lot next to the street [Downhill building]. For uphill buildings place at low end of building.

∞ Garage floor should be at least same elevation as street opposite the centre of the driveway and 300mm above street.
- Only when property is very valuable long driveway considered

∞ Location of front property line [see diagrams]

∞ Proximity to Adjacent buildings [affects privacy, views, retaining wall heights, entries/egresses]

∞ Drainage problems
- Direct water from roof and driveway to street, drainage canal or natural watercourse

∞ Street slope (building form solutions)

∞ Sewage system can affect building location

∞ Building formations (see diagram)

∞ Interior layout

∞ Stairs should almost always follow the grade

∞ Decks
- At least 1 along downhill wall
- 3-4m for sitting at a table
- 2-2.5m for sitting or sunbathing

(Levin 43-102)

5.0 ARCHITECTURAL

- 1.2m for walking out to see view
- Spaced decking for drainage (3mm)
- Make window washing simple and minimize or eliminate need for scaffolding during construction

∞ Bottom floor – serves many purposes

∞ Under floor
- Open or enclosed
- For open:
- Wood poles
- Tapered Steel or standard steel beams
- Glued-laminated beams
- Trusses
- An arch

∞ Building shape

∞ Soils report specifications – architect to coordinate with structural engineer concerning soils report

∞ Waterproofing (building walls adjacent to earth – thoroseal and sub drains covered with gravel)

∞ Design for change

(Levin 43-102)

6.0 SOIL AND GEOLOGY

∞ Report
- Stability of site
- Subsurface exploration results [types of soil, depth of man-made fill, depth of top soil, water table, geologic hazards, logs of test pits or boring results]
- Engineering parameters for retaining walls and footing
- Grading recommendations
- Recommendations for method of support of buildings and structures [foundation type and retaining walls]
- Clearances from ascending slopes
- Anticipated settlement of foundation
- Soil testing results from laboratory
- Recommendations for waterproofing rooms below grade
- Recommendations for drainage of roofs, slopes and pads
- Recommendations for sewerage where no sewer exists

∞ Observation of construction [site and foundation]

∞ Planting
- Plant roots eventually help prevent erosion
- Use recommended plants

(Levin 29-42)

7.0 STRUCTURAL

∞ Topography plan and Soils- Geology Report

∞ The downhill building
- Standard footing versus pile formation

∞ Minimum use of caissons or piles

∞ Pile diameter [a good diameter is 750mm]
- Retaining grade beams
- Planning the foundation
- Pile ties
- Floor framing and ties

∞ Wind effects

∞ Retaining

(Levin 103-146)

8.0 CONSTRUCTION

1. Removal of foliage
2. Soils and Geology Report – obtain
3. Survey and topography – mark property corners and prepare a topography plan, locate all piles, caissons, and retaining walls, spot check ground elevations
4. Grading
5. Piles: drilled or hand dug
6. Wood shoring
7. Excavation Inspection (soils geology consultant)
8. Placing reinforcing
9. Grade beam construction
10. Building inspection
11. Reinforced concrete production
12. Foundation Inserts
13. Special inspectors
14. Construction of building

(Levin 147)

Structural foundation options for pole houses

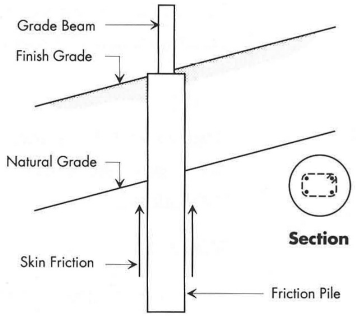


Figure 10: Friction pile poured in place - Arthur Levin

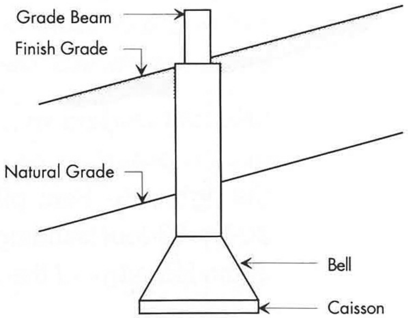


Figure 11: A belled caisson pile - Arthur Levin

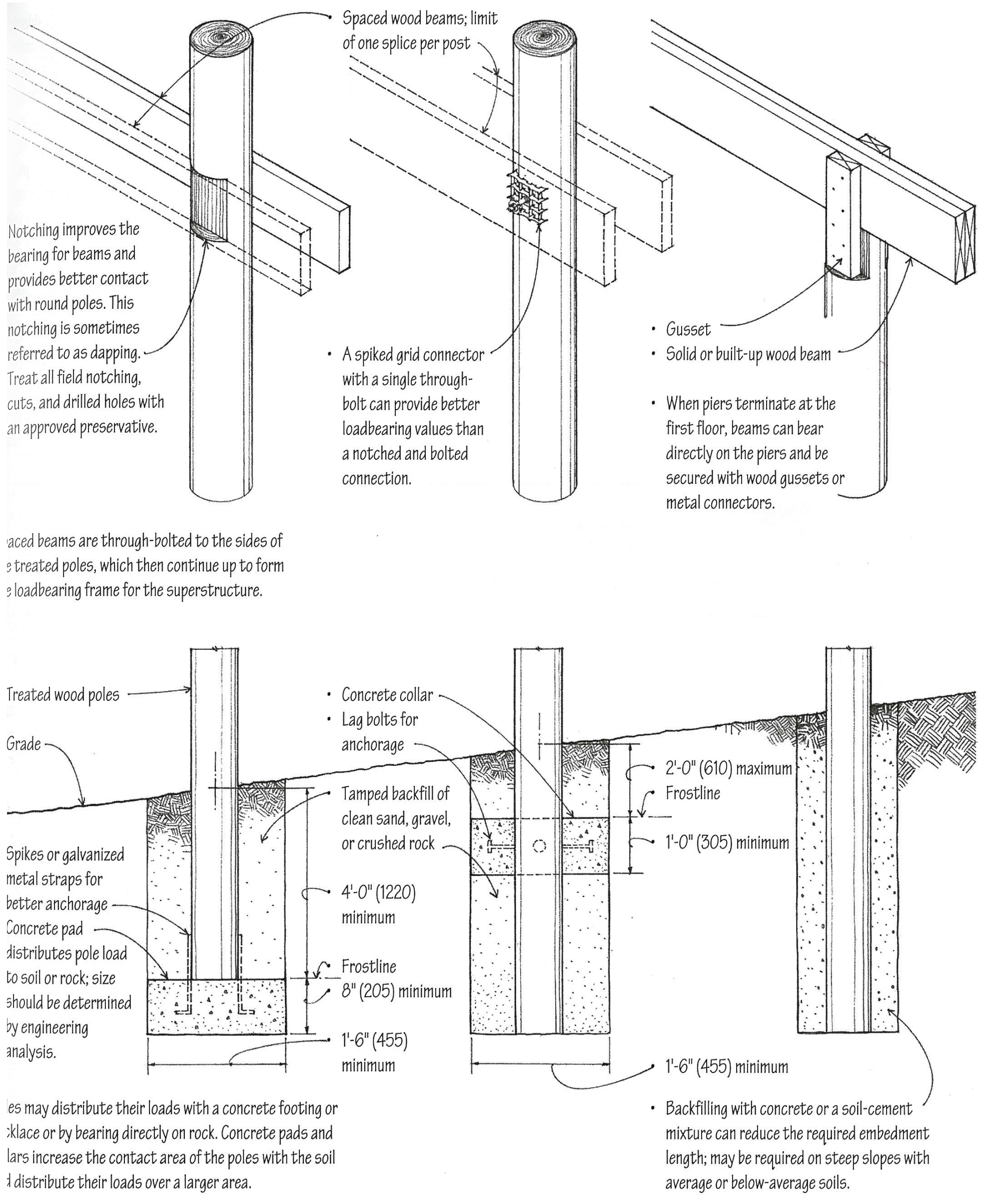


Figure 12: Pole Foundations - Francis Ching

Structural / Architectural options for pole houses [Levin]

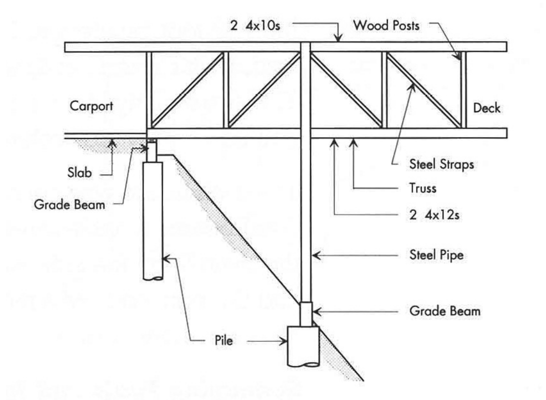


Figure 13: Arthur Levin

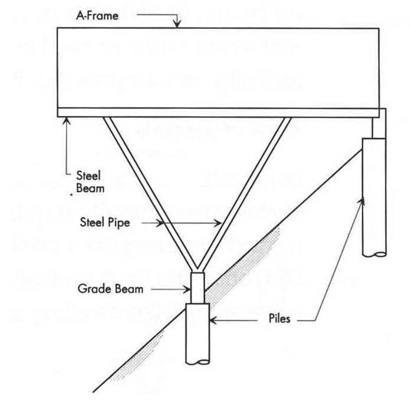


Figure 14: Arthur Levin

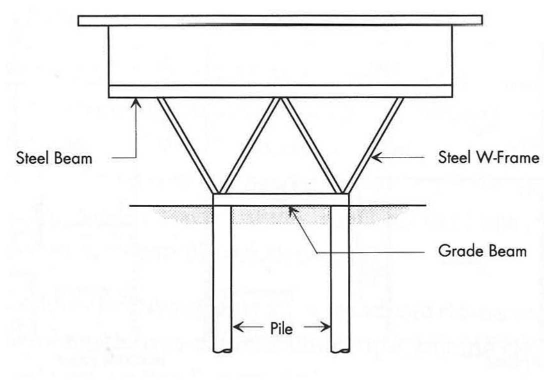


Figure 15: Arthur Levin

Truss + pipe + pile foundation

In this design, the truss allows the structure to cantilever far beyond the last foundation support giving a dramatic appeal. This design option is clearly viable for very steep slopes where grading would not be considered for logistic and site stability reasons. The truss could be of steel construction, delivered to site prefabricated and craned into place. I would like to see the truss challenge the rectilinear form and morph from the box into a more complex geometry which relates the design specifically to the site, and incorporate the pipe supports more. This truss could become a feature which is on display, solving the issue of windows conflicting with cross members visually.

Steel V frames supporting steel beams to support building on 4 caissons

The steel V frames are an interesting approach to supporting a hill site dwelling. The angles relate the structure to the incline more than purely upright poles. This type of supporting structure would certainly feature, and could become the foundation for modular units. Alternatively, this also works with the tapered typology in section, as a means of supporting the first floor while a ground floor occupied some of the space beneath.

Steel W frames supporting steel beams to support building on 4 caissons

The W frame would require careful consideration for the structure above in terms of architectural incorporation. The diagram illustrates the frames to be a very separate element from the form above, and for the design to link to the context, the footing should feed into it as a single element conceptually. For hill sites the footing is a significant design consideration and one which is unique to the site, therefore a structure which expresses an international prefabrication style with no relation to the context would be a disappointing object upon the pedestal.

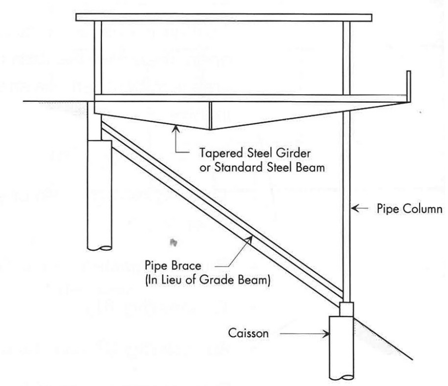


Figure 16: Arthur Levin

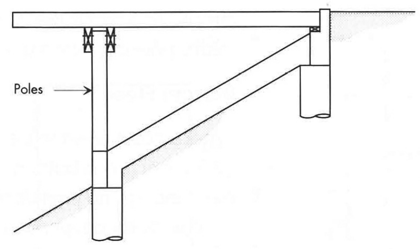


Figure 17: Arthur Levin

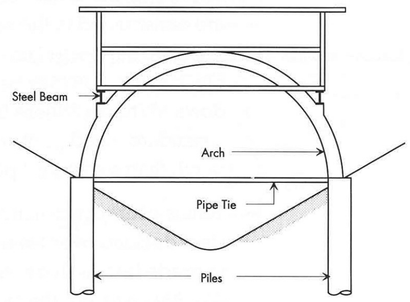


Figure 18: Arthur Levin

Tapered steel girders or standard steel beams are an option for an enclosed underside

The tapered steel girders are a form of structure which the architect would most likely intend to conceal. Overall the form of this structure does not stimulate a reaction of delight or celebration of the site, but rather appears ill proportioned.

Wooden poles

Wooden poles offer a cost effective means of construction and have been utilised in New Zealand for many years. If the underfloor space is to be concealed, wooden poles can be a good choice. However, there is opportunity for featuring them in an architectural design move, as shown in the Loblolly house where they appear scattered and slightly angled to reflect the nature of the pine trees surrounding the dwelling.

An arch [LVL]

The LVL arch is a bold design which will not be successful or possible for all hill terrains. Being quite site specific and a 'one off' design element; this will not be tested in design studies.

Concept designs for driveway / access to downhill building type [Levin]

Dependent on distance of building from street / frontline

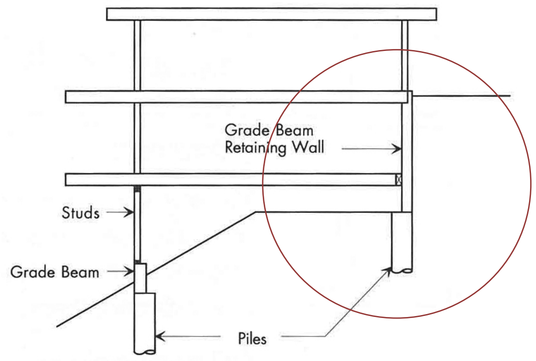


Figure 19: Arthur Levin

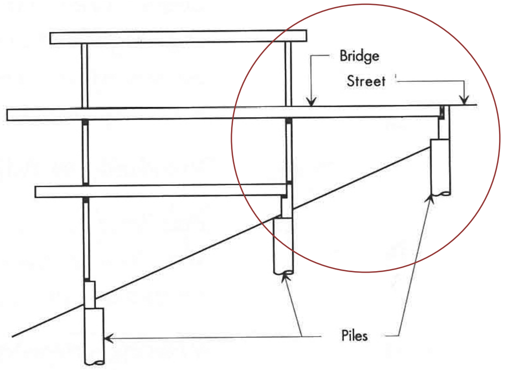


Figure 20: Arthur Levin

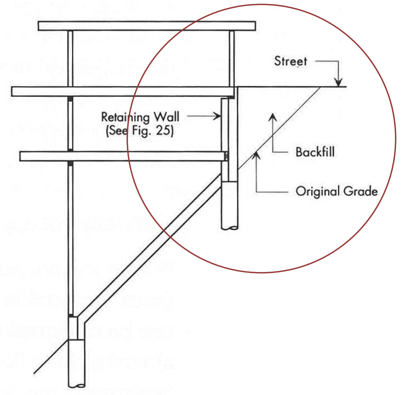


Figure 21: Arthur Levin

This design illustrates the building being placed very close to the street. It is a design option if the site boundaries restrict the house to this placement, but note how a significant retaining wall must form the back wall of the structure. This requires extensive grading, retaining structure and drainage systems. It would entail high site works expenses.

This second option illustrates the house positioned some distance from the street, with a bridge to access the dwelling. It is a very good solution as there is no grading required, nor retaining walls, thus great expense is spared. The topography itself is preserved as the building sits on the land and the natural water course is not altered. The bridge may be constructed of timber decking with spaces between the boards to allow the water to drain through. Architecturally, this bridge may be a featured design move and carefully planned to create an intriguing approach to the entry.

This design is similar to the previous one but contains backfill underneath the 'bridge' element. It would create an extra expense, not only for earth works, but the back wall of the ground floor must become a retaining wall and drainage issues must be resolved.

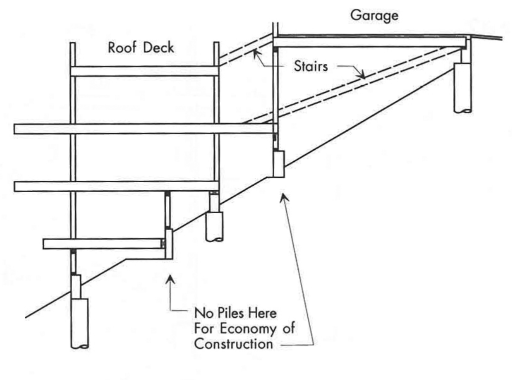


Figure 22: Arthur Levin

This last illustration of a downhill house places the dwelling quite far down the hill from the street. This can lead to a platform becoming the area for cars to park, and stairs would lead down from the street to the entry. A second set of stairs may lead to a roof garden. In this design, landscape architecture and planning would be as significant as the architecture itself. The advantage of such a design would be the element of seclusion from the street, as the house could be immersed in the trees. This design is complex and would likely be more expensive to construct than the previous options, but offers great architectural opportunity.

2.2. Prefabrication

Figure 23: Modern Modular - Resolution: 4 Architecture

In the key text *Prefab architecture: a guide to modular design*, the relationship between prefabricated houses and the prevalent architectural aesthetic they portray is questioned (Smith 251). "Prefabrication is a method of building," but it has become synonymous with the stylistic outcome of "modernist detached dwellings" (251). This marriage however is acknowledged by Ryan Smith as an "outgrowth of intention" rather than a technical requirement of prefabrication systems (251). One may question why prefabricated houses are conforming to a common aesthetic they are not bound to; and why architects are not utilising prefabrication to realise non-rectilinear forms. Contemporary architecture as a whole presents a wide variety of styles and form expressions which could translate to prefab.

This misconception of design flexibility can only be detrimental to the elevation of prefab housing in the building market. Not all clients wish to live in a box with a monolithic roof; but is there some logic to this form outcome? Transportation of modular units, whether by truck or shipping container, certainly imposes an envelope of dimensional limitations, and the cuboidal form optimises the envelope.

Smith proposes that "a meaningful discussion about the opportunities and challenges of offsite fabrication in architecture in a myriad of building types and conditions" is "what design culture needs" (252). My aim throughout this thesis is to enter into this discussion by creating a condition, the hill site, and a form type which challenges the rectilinear. To prove that a particular style is not a prerequisite for this construction technique.

Figure 24: BURST*008, MoMA, Home Delivery: Fabricating the Modern Dwelling. Side view - GA / Gauthier Architects

There is hope for this cause as recent developments in digital technology could enable “both variability and predictability within prefabrication” (252). The exhibition *Home Delivery: Fabricating the Modern Dwelling* that showed in 2008 at the Museum of Modern Art (MOMA) demonstrated that industrialization with customisation could potentially transform the building market (Smith 252). Modern prefab architects must know when to harness the standardization of assembly line production and when to use CNC technology to customise accordingly (255). There is much we can learn from Scandinavia about style verses production as they have been building prefabricated dwellings for decades. Today in Scandinavia, “a site built house is, bottom line, a more expensive house” (255).

Prefabrication has been promoted as being more cost efficient than other onsite methods of construction (Smith 81). This is because “cost consists of three aspects for which prefabrication potentially has solutions: material, labour and time” (81). Today, the construction industry is governed by the equation Q (quantity) x T (time) = S (scope) x C (cost). All variables must stay in balance, no matter which ones are given priority in a project.

A primary method to reduce cost is to reduce the amount of material implemented (Smith 81). “In onsite construction, materials are often over-ordered to ensure a quantity for the appropriate task is acquired” (81). However in a factory materials can be purchased for many projects in one order, a concept known as “Just in time” because the materials are present no sooner or later than needed (81). Sharing material resources over several projects not only reduces the overall material used, but reduces waste creating an environmental benefit.

In onsite construction, moving materials around a site due to limited space consumes contractor's time which increases the overall cost. While factory produced construction is quicker with the aid of CNC equipment, "just in time" materials, overlapping subcontracting and no weather restrictions; this does not necessarily produce an automatic decrease in cost. Factory overheads and the time taken for fabrication set-up incur costs. Increased transportation costs and craning can be expensive which may offset the savings of less onsite labour / construction time.

There are significant schedule savings reported when prefabrication is utilised in residential construction. Ryan Smith states:

> *"By going to a componentised system of prefabrication for housing, whether panels or modules, manufacturers can save substantial cost in schedule, material and labour" (254)*

> *"Michelle Kauffman reports that in her experience with prefabrication, comparing the first Glidehouse she built onsite using the stick and framed method to the second Glidehouse, prefabricated as a module offsite, the duration of the project was nearly half for the modular prefab"* (Smith 86)

The scale of prefabrication goes from components, to panels, to modules. "In general, it is desirable from an efficiency standpoint to move to manufacturing larger components, panels and modules to a greater degree of finish so that onsite erection is faster" (Smith 127). However, in the context of hillside sites where accessibility can cause issues, the joining of elements can be not desirable, nor feasible, until on the jobsite. "Panel construction has levels of finish at 60 percent while most modular systems are finished to 85 percent" (Smith 128).

The text Prefab Houses: Maisons Préfabriquées presents 23 prefabricated houses from around the world. The following diagrams were produced to illustrate the systems and materials each case study used to gauge global prefab technologies being instigated. It references architectural firms who have made headway in prefabricated housing over the past decade.

12 container house

Brooklin, Maine, USA

....Adam Kalkin

- + Stainless steel containers x 12
- + Concrete
- + Aluminium framed glazing
- + Steel framing
- + Corrugated aluminium roofing

(Sergi 10-17)

glidehouse

Novato, California, USA

.....................................MKD-Michelle Kaufmann Designs

- + Bamboo flooring
- + FSC-certified wood structure and finishes
- + Factory built components include frame structure, clerestory windows, cabinetry, glass façade, and exterior system of wooden sunshades
- + Modular category, transportable
- + Sustainable

(Sergi 42-49)

modular 4

Kansas City, Kansas, USA

....Studio 804

- + Reused aluminium in the foundation walls
- + Outer façade Brazilian teak wood slats sealed with organic polymer
- + Recycled aluminium panels used for exterior shutters
- + EPDM roofing membrane
- + Wall and ceiling insulation made from cellulose fibre from old newspapers
- + Modular construction, transportable

(Sergi 72-79)

Taylors Island, Maryland, USA

Cape Cod, Massachusetts, USA

MoMA, The Museum of Modern Art, New York, USA

Cleburne, Texas, USA

Santa Rosa, California, USA

Moab, Utah, USA

hidden valley house

....Marmol Radziner Prefab

- + Modular
- + 12 modules
- + Recycled steel frames
- + Low E Glass
- + Transported with windows, doors, cabinetry, photovoltaic panels, electric appliances and other exterior finishes already installed
- + Each module is sheathed with steel panels
- + Interior box is finished in walnut
- + Timber deck
- + Stone slabs used for interior flooring
- + Structural insulated panels [SIPs] form cladding

(Sergi 152-159)

cape house

....................................Resolution: 4 Architecture

- \+ Birch-clad shell [not prefabricated as part of modules]
- \+ Prefabricated elements consist of modules which consist of the wood panel covering, the windows, the bamboo flooring and the modular furniture
- \+ Prefabricated elements transported by road
- \+ Modular construction

(Sergi 112-119)

system 3

.... Oskar Leo Kaufmann, Albert Rüf

- \+ Each section of wall, floor or roof was fabricated from wooden units with a maximum length of 49ft.
- \+ CLT panels cut in a factory with CNC technology process the panels are coated using a boat seal to waterproof the exterior
- \+ Windows are then inserted. Fits into shipping container

(Sergi 182-189)

residence for a sculptor

.... Sander Architects

- \+ Concrete slabs used as flooring on the lower level
- \+ Bamboo flooring used on the upper level
- \+ Structure can be dismantled and recycled or reused
- \+ Aluminium cladding

(Sergi 174-181)

loblolly house

....................................KieranTimberlake Associates

- \+ Timber piles
- \+ Cedar clad façade
- \+ Structural elements completely prefabricated, assembled in situ
- \+ Aluminium structure
- \+ Fibre-cement panels
- \+ Wooden cladding [slats]
- \+ Interior finishes of Birch plywood panelling
- \+ All parts in kit can be assembled with a wrench, easily disassembled
- \+ Parts can be recycled in another structure
- \+ Core containing bathroom and facility room completely built in the factory
- \+ Double layered glass wall
- \+ Inner layer comprises folding glass doors; outer layer polycarbonate hangar-style shelters that work as a screen to protect against the rain

(Sergi 120-127)

farley studio

....M.J. Neal Architects

- \+ Metal structural insulated panels [SIPs]
- \+ Prefabricated skin double shell of polycarbonate and corrugated galvanised steel
- \+ Southern Yellow Pine plywood finish
- \+ Metal framing inside prefabricated casting panels is coated in white enamel
- \+ Blue glass façade
- \+ Concrete [foundation and floor]

(Sergi 26-33)

Figure 25: Diagram of prefabricated housing construction types, Author's Own

m2 kip house

....Kim Herforth Nielsen/3XN

+ Catalogue-order home
+ Structure is concrete
+ Can be clad with either timber or cement
+ Wooden floor
+ Glass façade with aluminium joinery
+ Black tar-paper is used on the roofing

(Sergi 138-145)

house s

Charbonnières-les-bains, France

....Korteknie Stuhlmacher Architecten

+ Timber exterior cladding
+ Timber interior surfaces
+ Concrete foundations and floor finish
+ Structure is prefabricated CLT panels factory cut
+ Outer wall and roof skin is made from deal laminate panels [3.34 and 11.4 in. thick]
+ Aluminium window joinery

(Sergi 34-41)

house braun-dubuis

Disentis, Switzerland

....Atelier Werner Schmidt

+ Concrete foundations [4 in. bed]
+ Straw bales manually tied together with plastic strips on site
+ Interior and exterior walls whitewashed
+ Ground floor finished with natural flagstones
+ Corrugated aluminium roof
+ Prefabricated wooden windows and doors
+ Prefabricated kitchen, bathroom and flooring

(Sergi 50-55)

black box

Krainhagen, Hannover, Germany

....Matthias R Schmalohr

+ Concrete foundations
+ Exposed concrete panels
+ Timber framed structure with plywood interior lining
+ Waterproof plywood with inner cellulose insulation
+ Aluminium window joinery
+ Timber flooring

(Sergi 80-87)

house of huts

Breda, The Netherlands

....Studio NL-D

+ Insulated stainless steel shell
+ Outer skin of sandwich panels incorporating climatic control system
+ Glass façade with aluminium framing
+ Steel framing scaffold primary structural system
+ Timber members to cross frame steel members
+ Timber floor

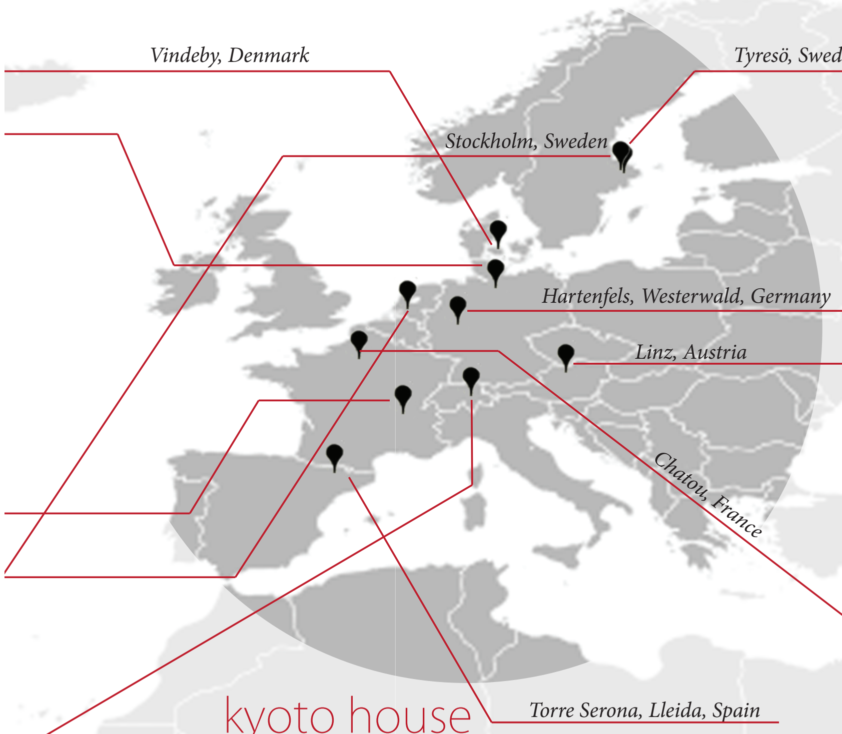
(Sergi 98-105)

next house collection théa

....Magnus Ståhl

+ Pre-cut wood panels
+ Prefabricated kitchen and bathrooms
+ Catalogue order prefabricated dwellings
+ Timber façade, decking, interior floors
+ Aluminium window joinery

(Sergi 56-61)



kyoto house

.... Pich-Aguilera

- + Entire structure and composition of the building is prefabricated from concrete slabs
- + Adjustable aluminium or wood panels in openings in the façade act as solar protection elements
- + Insulating material with low environmental impact is used such as glass wool or from renewable materials like cork or wood
- + Concrete used like a jigsaw with columns which contain tongue elements for the inset panels to slot onto. Steel fasteners
- + Between the inner and outer panels there is a ventilated chamber with insulation
- + Concrete pillars and main beam structure
- + Prefabricated concrete stairs
- + Photovoltaic panels
- + Corrugated aluminium roof

(Sergi 168-173)

plus house

....Claesson Koivisto Rune

- + Prefabricated wooden components from sustainable forest projects [superstructure, cladding, panels, decking]
- + Aluminium framed carpentry

(Sergi 18-25)

house m

.....................................Caramel Architekten

- + Wood finish platform
- + Prefabricated insulated panels
- + Synthetic membrane: EPDM on the roof
- + Synthetic membrane: white Teflon-coated PVC on the walls
- + Steel columns

(Sergi 146-151)

huf fachwerkhaus 2000 art 9

.....................................Manfred Adams, Huf Haus

- + Catalogue order houses with bioclimatic designs
- + Wood structural frame with mineral-wool insulation
- + Concrete basement
- + Glass monitor roof with photovoltaic panels
- + Radiant floor

(Sergi 160-167)

the floating house

.....................................Ronan and Erwan Bouroullec

- + Wooden frame
- + Aluminium roof
- + Interior walls and ceiling timber boards
- + Timber floor

(Sergi 106-111)

Figure 26: Diagram of prefabricated housing construction types, Author's Own

x house

....Arquitectura X

- Concrete plinth
- Stainless steel skin
- Lined with plywood panelling
  [cut to size in factory and screwed onto structure]
- Polycarbonate panels white
- Steel structure prefabricated 20-ft.-long rectangular sections steel framing [industrial]
- Steel walls bought in standard sizes mounted in situ onto structure
- Partitions polycarbonate and sandblasted glass
- Flooring: plywood and white polished concrete

(Sergi 62-71)

wall house

....Atelier Werner Schmidt

- Exterior factory sewn soft skin with solar protection coating similar to those used in greenhouses which reflect 50-70% of solar rays
- Prefabricated stacked shelving
- Polycarbonate milky shell
- Double glass with sliding doors and pivoting glass panels
- Concrete nucleus
- CLT panels
- Large timber trusses
- Steel framing to support polycarbonate panels and soft outer membrane

(Sergi 128-137)

r. r. house

.............................Andrade Morettin Associated Architects

- Wooden structure [framing]
- Prefabricated timber roof
- Steel finished with slats of expanded polystyrene [EPS]
- Pivoting fibreglass panels with PVC coating

(Sergi 88-97)

In order to comprehend the full scope of prefabrication opportunity in New Zealand, the text Kiwi Prefab: from cottage to cutting edge proved invaluable. The following page documents a diagram I assembled to express a summary of the information found within this text on prefabrication systems available in this country.

It was found the opportunities for prefabrication in New Zealand are similar to the technologies utilised overseas for component and panel prefab. However, the modular industry is not well established here. By utilising hybrid prefabrication we can maintain the design flexibility and customisation of panel prefab with modular bathroom units. This will enable the residential architecture to be designed to fit the particular terrain and site conditions.

Figure 27 (opposite page): Diagram of prefabricated housing construction types
- Author's Own

Prefab housing with architecturally designed ties

Box living [Tim Dorrington]
Ekokit
Bachkit
Lockwood
(Bell, Southcombe 65)

Architectural firms designing custom prefab houses

Assembly
Jazmax
Studio Pacific
Herriot Melhuish
Geoff Fletcher
Gerald Parsonson
Tennant+Brown
Wilson & Hill
(Bell, Southcombe 65)

SCALE OF PREFABRICATION >> >>

Component based prefab [kitset]

Pre-engineered, pre-cut and pre-nailed roof trusses
Pre-cut and pre-nailed framing
Roll formed pre-cut steel framing and trusses
Laminated timber joists and beams
Structural steel frames
Window and door joinery system
Cabinetry built away from site
Precast concrete technology
(Bell, Southcombe 64-70)

Panel prefab

Frame-plus-board panel systems
Solidwood panel
Structural insulated panels (SIPs)
Timber Structural Insulated panels (SIPs)
Cross laminated timber (CLT)
Precast concrete panels
Sandwich-panel systems
Light gauge steel based composite
Triboard
Durapanel
(Bell, Southcombe 70-76)

Prefab housing with architecturally designed ties

High performance house
Tilt panel house
(Bell, Southcombe 75-76)

"New Zealand does not have an established modular housing industry" (Bell 76)

>>

Kiwi Prefab: Cottage to cutting edge

Hybrid Prefab

= modular + panel
(Bell, Southcombe 81-82)

Modular Prefab

Container house
De Geest Construction
Stanley modular
(Bell, Southcombe 76-80)

Complete building prefab

Mobile homes
Laing Homes
Habode and i-houz
Port-a-bach
Koastline beachouses
iPad
(Bell, Southcombe 82-91)

Figure 28: Diagram of prefabricated housing construction types in New Zealand - Author's Own

2.3. Establishing an Aesthetic: Norway

Figure 29: Loen, a small village on the Western coast of Norway - Aqwis

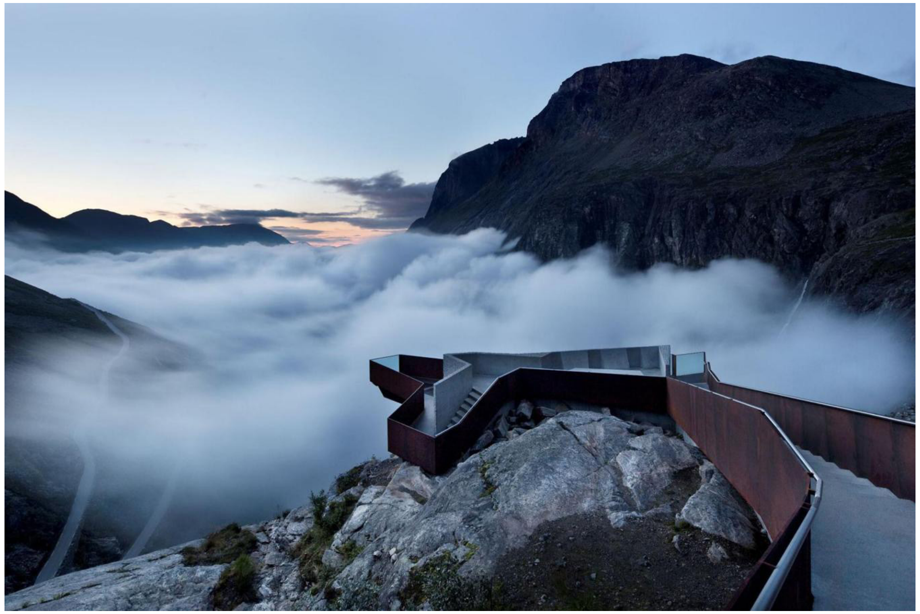
To establish design principles which would govern the aesthetic of design outcomes, I looked to Scandinavian architecture. Norwegian contemporary architecture in particular emerged as a fitting precedent. The limited palette of materials, articulation of form and connection between the architecture and natural landscape of Norway appealed to me. Parallels in culture, geomorphology and the resonation of design incentives between New Zealand and Norway became apparent throughout the research. I decided to reference a number of Norwegian designs to inform the work in this thesis.

Norwegian architecture is relatively less understood than that of the other Scandinavian nations. With little over 5 million people and a land area comparable to the size of New Zealand, Norway's economy and population has been dispersed due to the topography and geology of the land. The mountainous regions, fjords, coastlands and forests are intrinsic to the identity of Norway.

There is a likeness between the ways Norwegians perceive their natural landscape and how we, as New Zealander's, identify with ours. Renowned Norwegian architect and Pritzer Prize awardee Sverre Fehn defines Norway's "untouched" landscape as "harsh," "untamed' and unlike nature in many other places where "cultivated land" is the norm (Almaas 42). He goes on to describe Norwegian's relationship with nature as an "active one" which is escaped into "as often as we can" (42).

You could say there is an affinity between New Zealand's national identity, which presents a cherishes remnants of the dramatic unspoiled and untouched landscape, and the way in which Norway presents their image to the world. We too form connections to the landscape by experiencing it; escaping into nature, which is never too far away. One could argue that, in this respect, Norway presents a more fitting reference than the architecture we inherited from the United Kingdom. The majority of Britain's natural landscape is pastoral; they lack the drama of mountains. Even in the context of Wellington city we have the natural untamed bush, which feeds into the city as the town belt, the rocky coastlines and extreme winds. Norway's wild landscape evidences their architecture to be a fitting reference to amend our architectural practice philosophy.

One of the central motivations of this thesis is to explore how prefabricated residential architecture can interact with the landscape, namely severe topography. The architecture of Norway has provided limitless case studies expressing this notion. The question "how do we respond to the natural landscape?" is one which has characterised Norwegian architecture to date (Gahr Store 7). Nordic architecture is traditionally acclaimed as natural and authentic with a particular sensitivity to the locality where the building is placed (Hvattum 100). If we consider the historical architectural thought, much of the Norwegian architecture debate over the past three decades of the 20th century circled around the concept of genius loci – the spirit of place (Skotte 11). Kenneth Frampton introduced a discourse on the term "critical regionalism," a term also rooted in an understanding of local conditions as the source and meaning of architecture (Helsing Almaas 8). It was conceived that the "topographical and climatic specificity" of a place constituted a moral imperative for architecture and "a measure of its authenticity" (Hvattum 107).



More recently however, young Nordic architects are reinterpreting the relationship with place and view, taking a larger, broader perspective (Hvattum 100) To clarify, the historical theories were more literal than the contemporary insights, for example, a building may be considered successful it if appeared to "grow" from the ground like the trees it was constructed from; architecturally speaking. Hvattum's article *Making Place in the text New Nordic: architecture and identity* discusses how contemporary Norwegian architects are reinterpreting this notion and distancing themselves from the traditional established understanding.

Immerging is a kind of "contextulism" rather than "naturalness" because architecture is by definition constructed artificial and complex (Hvattum 103, 115). "There is nothing natural about the precise geometry, the careful manipulation of materials[…]or the highly cultivated plans" (115). Architecture must also be more than a "mimetic re-enactment of topographical form" but reinterpret the meaning of both nature and place (115).

One project which corroborates a particular affinity to place and "more than any other" seems to illustrate the "intimate link between nature [and] place" is the Norwegian Tourist Routes project (Hvattum 113). While these structures are not related to residential architecture, the concepts regarding how they relate to the environment they are situated in is transferable.

Young architects and designers were commissioned by the Norwegian Public Roads Administration to design rest stops and lookout points; the aim being to develop 18 routes across Norway, each presenting characteristic features of the Norwegian landscape while showcasing contemporary Nordic architecture

Figure 30: The Trollstigen Plateau Walkway - Reiulf Ramstad Arkitekter (RAA)

Figure 31: The Visitor Centre, Trollstigen National Tourist Routes Project - Reiulf Ramstad Arkitekter (RAA)

Figure 32: Maritime Youth House - JVA. Photography by Paolo Rosselli

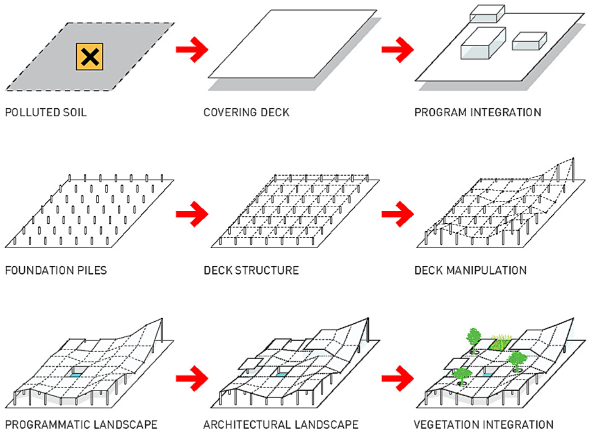


Figure 33: Diagram of Maritime Youth House - JVA

(Hvattum 113). I have selected four examples which are displayed on the following pages along with short descriptions of how the designs have been contextulised.

Relating to the ground

The relationship between the form or platform and the ground is one which has occupied my thought greatly during the course of this thesis. Three projects emerged as thought-provoking examples of how the architects have grappled with this concept; the first two are works by Jarmund/Vigsnaes (JVA) which reside above the land. The Science Centre at the University of Svalbard is lifted up on stilts, allowing it to tip toe above the ground without touching it thermally, thus preventing the building from thawing the frozen soil (permafrost) (Hvattum 107). The second project, JVA's design for Maritime Youth House also tip toed on the land. The ground where this youth centre was to be situated was polluted, so instead of spending a quarter of the budget removing the heavy metals, the project "floats" above the ground leaving the toxin soil untouched and creating a second layer of nature (Fig. 33) (Hvattum 108).

The third project I wish to pay reference to is Cabin Vardenhaugen by Fantastic Norway. This coastal cabin is placed on an outcrop of flat rock by the Atlantic Ocean (Almaas 82). The form of the building "lies snugly along a low mountain ridge" anchored with steel cables to the exposed bedrock (82). This structure, like the previous two, does not scar the landscape but rather sits respectfully upon it. To cope with the extreme environment, the black roof has been

Figure 34: Cabin Verdehaugen - Fantastic Norway

designed to fold down to become a wall on the sides most exposed to the weather. The wall surfaces are angled to prevent the wind from taking hold, a design concept which could be instigated in Wellington's windiest sectors. In the context of this thesis, hillside structures are faced with amplified wind conditions, wind loading being a significant design factor. This project poses an ideal precedent for later reference.

These three projects certainly reinterpret what it means to relate to the ground, the landscape and the context.

Figure 35: Cabin Verdehaugen - Fantastic Norway

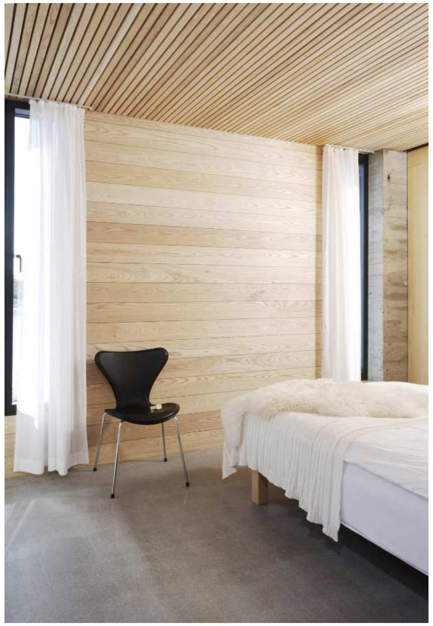


Figure 36: Summer House Skatoy, Norway - Filter Arkitekter As

Figure 37: Summer House Skatoy, Norway - Filter Arkitekter As

Materials

The elegantly simple articulation of materials is one of the major characteristics of Norwegian architecture which appealed to this thesis. Whenever Norwegian architecture is presented by the international press, writers tend to emphasis the "honest" use of materials and "didactic clarity of the tectonic composition" (Hvattum 103). This evokes a desirable sense of authenticity. In Norway, it was "wood that was revered as the native and natural material" which had grown out of the natural landscape, the mountains and the forests to form a place specific building tradition" (Hvattum 107).

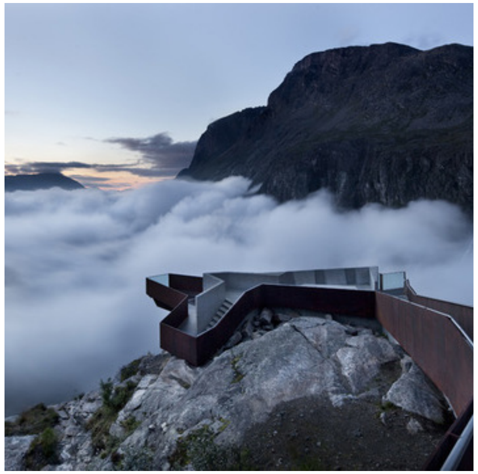


Figure 38: The Trollstigen Plateau Walkway - Reiulf Ramstad Arkitekter (RAA)

Figure 39: Norwegian Wild Reindeer Centre Pavilion - Snøhetta Oslo AS. Photography by Ketil Jacobsen

Figure 40: The Visitor Centre, Trollstigen National Tourist Routes Project - Reiulf Ramstad Arkitekter (RAA)

"Made of a combination of concrete, steel and glass, the structure fuses perfectly with the surrounding environment. Its harmonious nature comes from the use of indigenous looking materials. The cor-ten steel, also known as weathering steel, allows for the structure to blend into its surroundings at a distance. The route's severe curves resemble the fluidity of continuously moving water. This structure's intriguing design enhances the existing terrain, without distracting from it."

- Alpolic

"This unique natural, cultural and mythical landscape has formed the basis of the architectural idea. The building design is based on a rigid outer shell and an organic inner core. The south facing exterior wall and the interior create a protected and warm gathering place, while still preserving the visitor's view of the spectacular panorama."

- Snøhetta

Reiulf Ramstad Architects have an ambition to "create a contemporary architecture-based analysis of the site, from which emerges a sensitive interpretation of these conditions" (Vinnitskaya).

This building was designed to reflect the shapes of surrounding mountain peaks. The two shells of glass, steel and concrete were designed to resist this incredibly harsh of climate.

The buildings finishes alternate between being as smooth as ice to as rough as the rocks, echoing the nature of the surrounding landscape.

Figure 41: Cabin Verdehaugen - Fantastic Norway

"To provide maximum protection for the cabin, the black roof is folded down to become a wall on the sides most exposed to the weather. The wall surfaces are angled to prevent the wind from taking hold."
"A variety of sheltered outdoor spaces enables a dynamic and social relation between the cabin and the surrounding landscape."

- Fantastic Norway

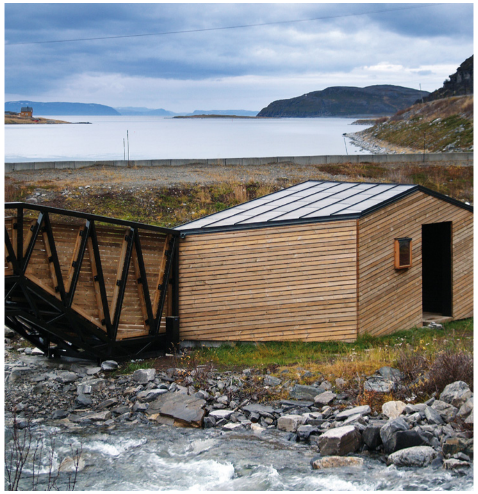


Figure 42: Lillefjord Rest area & footbridge - Pushak arkitekter. Photography by Werner Harstad

"The new bridge was our proposal; it works as a sign towards the trail, while at the same time taking care of all the demanded functions. It is leading on to an older trail, crossing the soft, green carpet of vegetation in the midst of the river deltae. By placing all the program in the bridge, the road stop installation is now a distinct object placed in the landscape. This felt appropriate for the rough and grand nature of the site, rather than small furniture placed around or in the ground."

- Pushak

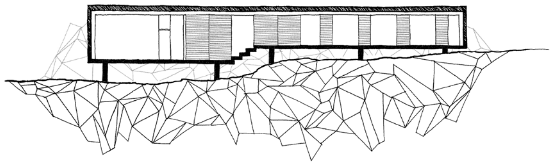
Figure 43: Svalbard Science Centre - Jarmund/Vigsnæs Architects (JVA). Photography by Nils Petter Dale

"The insulated copper-clad skin is wrapped around the program demanded, creating an outer shell adjusted to the flows of wind and snow passing through the site. Climatic 3D simulations has been undertaken to assure that the accumulation of snow would not create undesired conditions in front of doors and windows. In the process, the skin has been flexible to adjustments, both geometrical changes answering to the climatic studies and alterations of program. The building is elevated on poles to prevent the melting of the permanent frost – the only thing fixating the construction."

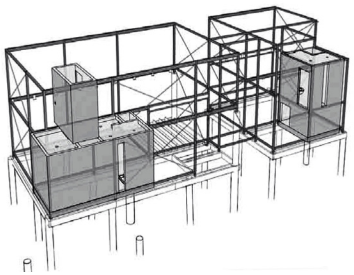
- JVA

3 Design Explorations

3.1. Design Study One: Platform



Hill Typology



+

Loblolly Prefab

+

Norway Precedent

Selecting a typology

The selection of the traversing typology from the matrix established earlier was based upon both geotechnical engineering information and suitability for appropriation of the Loblolly construction system.

It is advised in the research paper *The Engineering Aspects of Hill-Site Development* that the stability of a hillside is less compromised when the platform of a house is built across the slope, rather than protruding out from the incline (Sew 3). The reason for this lies with landslides. If a house suspends outwards from the slope its foundation system comprises of supports with vastly different height differentials along the gradient. This can cause the lower footings to move independently from the upper, which may remain intact, effectively pulling the house apart (Sew 3). Thus as evidenced, this design typology is more suitable for potentially unstable hillsides as the foundation system minimises the pressure placed on the hillside below the lower footings and subsequently decreases the landslide potential (Sew 3). Where possible, the planning of the foundation should aim to suit the natural contours (3).

In addition, it is good practice for slope stability to construct buildings with extended columns, rather than filling a platform (Sew 3). There are significant cost savings when major excavation, the subsequent construction of retaining walls, and the addition of fill is avoided. Pole houses evade scaring of the site.

By orientating the building across the slope, parallel to the contours, the vertically cantilevered foundation poles are naturally minimal in height.

Figure 44: Author's own

Figure 45: The Loblolly House - Kieran Timberlake

Figure 46: Flotane rest stop - L J B

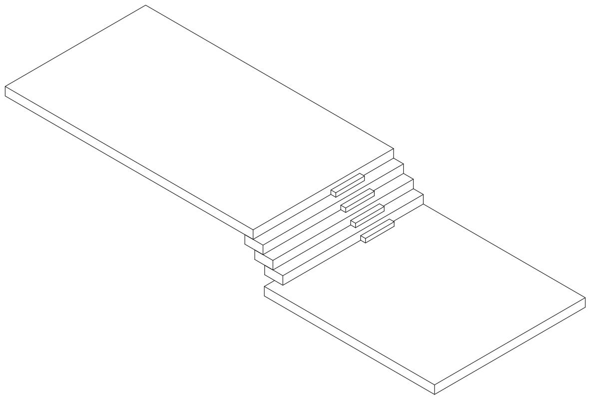


Figure 47: House floor plate to demonstrate steps as nucleus of house, seating area and transition point - Author's own

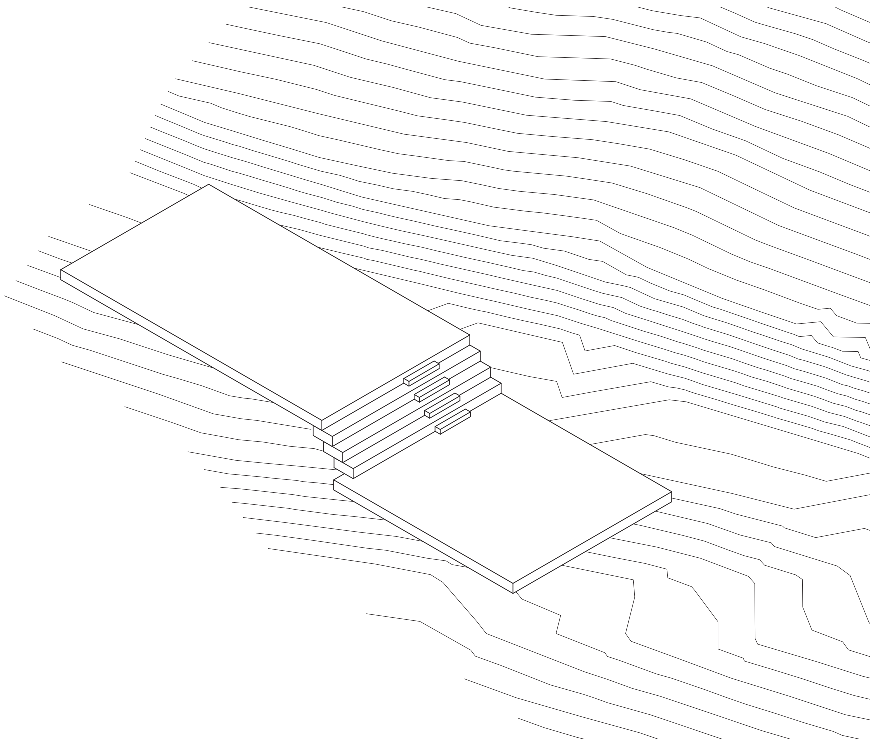


Figure 48: Relationship between floor plate and hill side - Author's own

Francis Ching states that the shorter the unsupported height, the more slender the poles can be (Ching 3.22). Thus, in this scenario where the building runs across the slope, more slender poles can be instigated. Shorter and more slender poles which are obscure can be argued as more desirable aesthetically and architecturally. Furthermore, if the alternative foundation system is desired and the structure is to be slotted into the slope, less excavation and thus lower retaining walls will be required, an additional financial benefit.

Prefabrication

This form type can utilise the same prefabrication construction system as the Loblolly house. An alluminium frame with cross braces will form the main structure; a scaffold. This will be connected to timber bearers supported by the roundwood posts. The scaffold is made up of Bosh 90 series profiles which are bolted with a T slot connection (Smith 297). This system allows for ease of assembly and disassembly.

Features of design

How can the incline be inhabited through architecture?

The aim of this design was to entice dwelling on the inclined plane to form

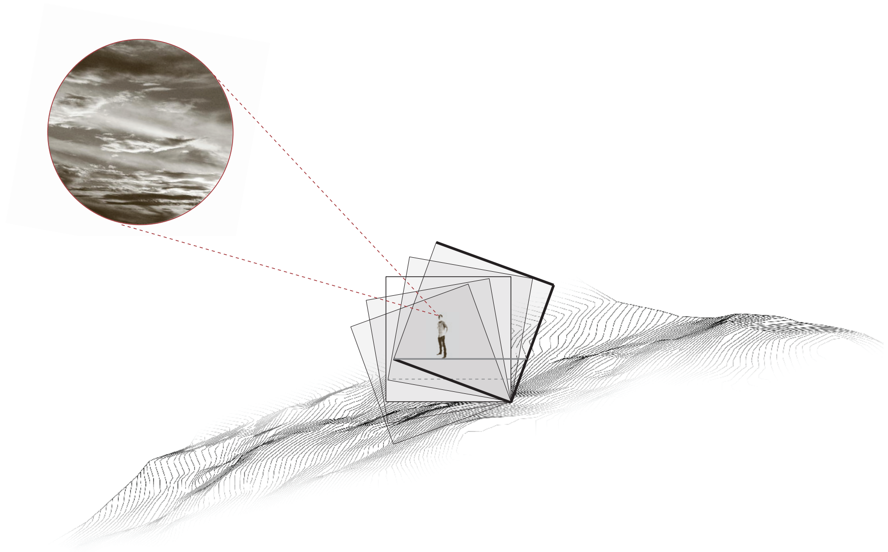


Figure 49: Tilting house upward to focus outlook on sky - Author's own

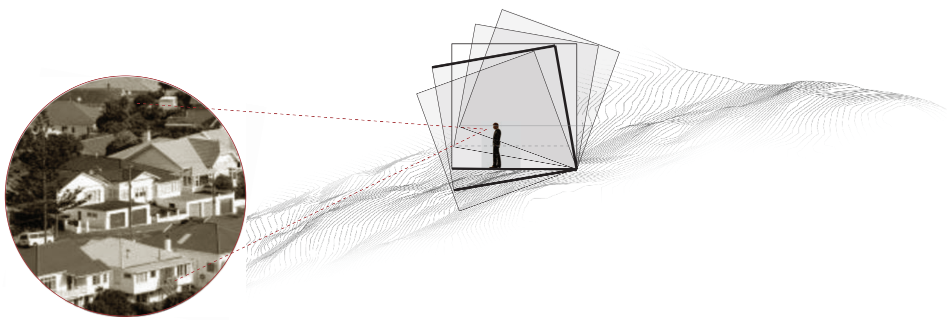


Figure 50: Tilting house downwards to focus view down-hill to land - Author's own

a connection between the occupant and the hillside. The incentive behind forming such a connection was a direct influence of Norwegian architectural ideas as outlined in the previous chapter. To resolve this concept, the platform was split and offset, creating a transitory moment between the upper platform and the lower. A stair would connect the two levels while mimicking the slope of the hill. However, in general residential staircases support transitory motion, not prolonged habitation. They are an element which support movement and discourage lingering. The design required the inhabitant to dwell on the incline, thus, by creating a stepped seating area which the stair built upon, this intention could be achieved.

This level change was positioned at the nucleus of the house, forming a clear divide between the living space (public) and the elevated, more private areas of the house (bedrooms and bathrooms). By positioning the level transition between the kitchen/dining area and the living area, it encourages high usage, being at the centre of the most occupied areas. One could argue this design move embodies the concept of 'hearth'.

The second design move considered direction of view. The level change had enabled a high ceiling in the living area, the side facing the view flanked with floor to ceiling glass. But rather than simply encourage a horizontal eye line, the form was rotated so the inhabitant would experience an alternative outlook.

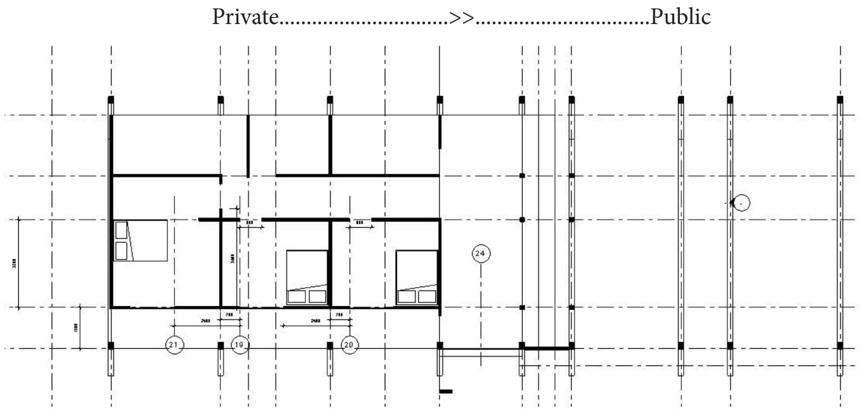


Figure 51: Plan - Author's own

Figure 52: Render of concept - Author's own

Conclusion

Overall, the degree to which the inhabitants would experience the incline is minimal. There is opportunity to further develop this idea to emphasis living on the incline further. From a typological standpoint, this does not deviate greatly from flat site construction. Houses on flat sites can often include slight changes in level to add a further layer of interest to the planning. As the house runs across the hill, the effect of the slope on planning is minimized.

This form does not challenge the rectilinear geometry which has become synonymous with modernist prefab dwellings. It could be developed towards a more Euclidean geometric form which is a response to the particular context. This house gives the impression of a generic design which could be applied to almost any hill site; a universal entity.

I am less inclined to lean towards the use of aluminum, as timber has a much lower embodied energy and is essentially a carbon bank. Timber also harks to traditional New Zealand architectural construction. In Norway, it is used extensively as a locally available resource and it's 'naturalness' relates the contemporary architecture to the surrounding environment. In future studies I explore this further.

1. kitchen
2. dining
3. living
4. bathroom
5. laundry/toilet
6. bedroom
7. deck

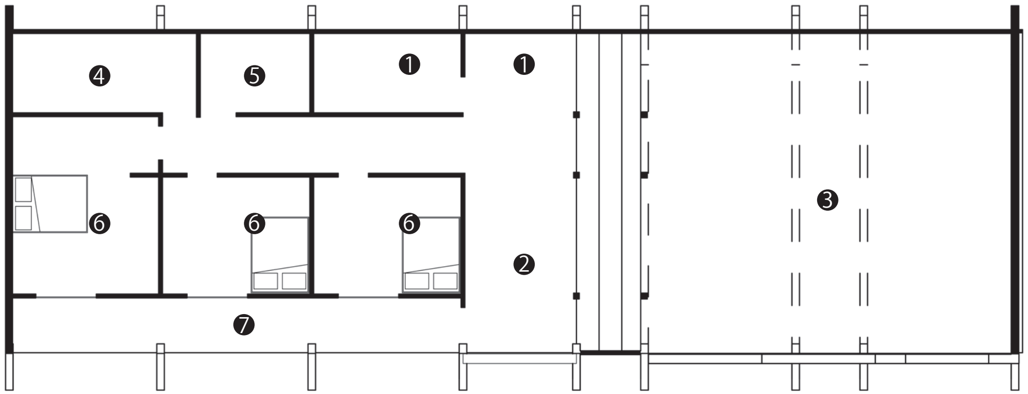


Figure 53: Plan - Author's own
Scale 1:200 at A4
1:100 at A2

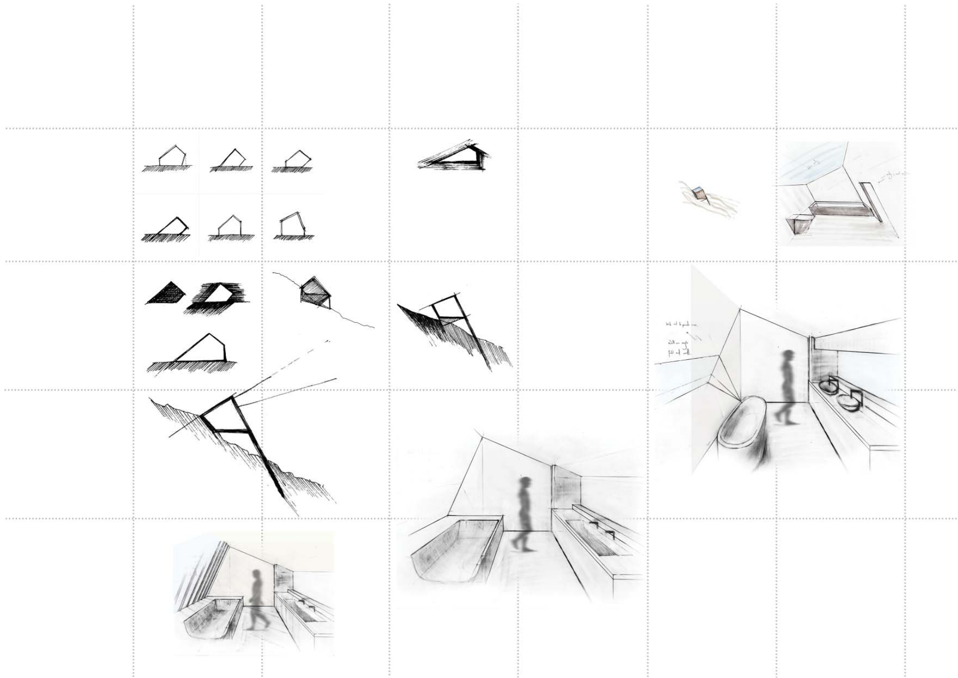
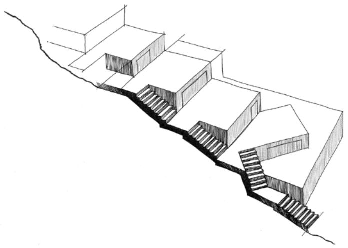


Figure 54: Sample of development sketches - Author's own

3.2. Design Study Two: Form



Hill Typology

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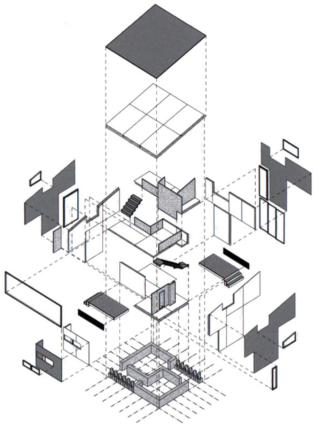

Jigsaw House

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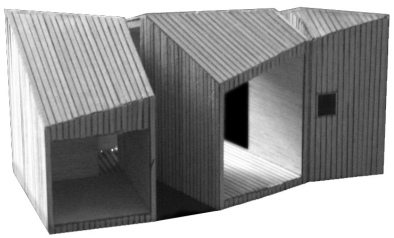


Precedent

Selecting a typology

The stepped typology was selected for the second design study because it provided an opportunity to advance the former design intention. The aim was to intensify the experience of inhabiting the hill side by extracting the transition between levels to the exterior of the dwelling.

This design move brings the inhabitants closer to the landscape which the house tentatively rests upon by enclosing the staircases in glass and allowing the stair to follow the gradient of the incline. The transparency of this transitional experience places the occupant within the changing seasons, lighting and foliage while contrastingly, the pods provide a sense of solidity and shelter. The form of the pods began as solids which were sliced to create the irregular roof geometry and punched into to allow light in at critical moments.

Prefabrication

The prefabrication system envisaged for this project was influenced by the Mark Southcombe's Jigsaw House. A panelised system of CLT timber would come together, much like a puzzle, to fabricate the pods.

Figure 55: Author's own

Figure 56: Jigsaw house exploded axonometric - Mark Southcombe

Figure 57: Sauna Ranco concept model - Panorama architects

Figure 58: Plan- Author's own

Figure 59: Concept render - Author's own

When considering the process of onsite erection, the issue of site accessibility arose. Being a downhill typology, the garage is at the top of the hill and is accessible via the road. If large CLT panels are to form the main structure, a knuckle boom, truck mounted crane (HiAb) would be required to lift the panels into place. The distance between the road and the third pod at the lower end of the incline may not be reachable with the crane arm. While some Knuckle boom cranes have reach spans of up to 40m, the lifting weight capacity decreases the further the crane arm extends. CLT panels can be relatively heavy and the panels can exceed 1 tonne (Xlam).

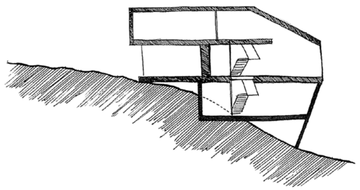
Features of the design

The planning illustrates a progression down the hill. The garage and entry are located at the highest level, closest to the street for accessibility. This pod also requires the minimum degree of privacy. A glass enclosed walkway leads the occupant out of this pod and down the hill towards the next pod which contains the children's quarters. The last pod houses the living space, kitchen and a mezzanine floor containing a master bedroom, en-suite and study.

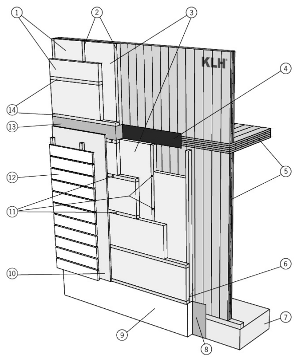
Reflection

The form relates well to the slope reflecting the almost faceted nature of hill sides. But being a generalized design test with no specific site set, contextualization is not expressed. The proportions of the overall design could be improved if the house was modified for a double income couple without children, removing the mezzanine so the house becomes a two bedroom home. With these modifications, modular design could be considered but the issue of access would have to be carefully resolved.

3.3. Developed Design: Aperture



Hill Typology



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KLH prefab

+

Norway Precedent

Selecting a typology

The tapered typology with angled planes was selected for the third and final study, as the form itself challenges linear design while responding to the inclined planes of the terrain. I saw this typology as an opportunity to rethink the pole house. The design could almost appear nestled into the ground like a 'cut and fill' house; but instead, sit upon the slope supported by a pole foundation system. The poles would be concealed by the cladding which would continue downwards to almost meet the slope. So long as a small gap was left between the cladding and the ground plane, this house would not disrupt the natural course of water running down the slope and thus, drainage would not create issues.

This study involved the development of five houses, each of which utilised the tapered typology, but responded to unique sites. In constructing five houses, material sharing could occur within the factory and set-up costs for the machinery would be divided among the houses.

Construction system

Foundation

Pole houses have a tradition in New Zealand due to their economic viability

Figure 60: Author's own   Figure 61: CLT construction detail - KLH

Figure 62: Cabin Verdehaugen - Fantastic Norway

and ease of construction. Digging holes to insert tree trunk posts was less laborious than cutting into the hillside to create a flat building platform (which additionally requires retaining walls to support the earth above). Today, with the aid of modern machinery, this can be a very efficient and economical way of providing footings for hillside houses.

Poled foundations involve specific engineering design, and the project engineer would refer to AS/NZS1170 (loadings code) and NZS3604 (timber code) among other things. The following paragraphs cover the basic concepts for timber round wood foundations to illustrate this significant part of the construction process. The information is compiled from an interview with structural engineer John Mackenzie, reference to concepts within the timber code, NZS3604 and lastly Levin's Hillside houses: Design and construction.

There are three options for timber pole construction; holes can either be bored, hand dug or the posts can be driven into the ground.

Figure 63 : Rotary Auger for boring piles - Amplus Ltd

If the piles are to be bored, a rotary auger is fitted to a digger to bore vertical channels. A digger can generally manoeuvre on slopes up to 30 degrees, if the slope is steeper however, a larger digger would be required with an arm span long enough to reach the site from the road. A number of pile borers available that have spans which reach up to 40m, however the larger the vehicle, the more costly it is to hire. Piles must be bored until they reach firm ground; the precise depth would be advised in a soils report from the structural engineer (Levin 44). For poor ground conditions, piles may need to be bored until they reach bedrock, where the posts are keyed into the rock for a firm footing. In good ground, the pile depth should be a minimum of 1200mm, but go deeper

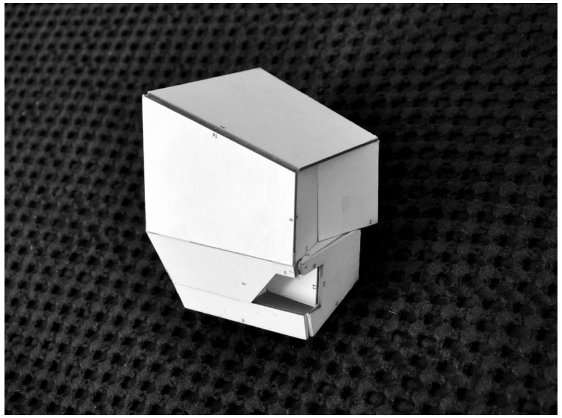


Figure 64 : Concept model- Author's own

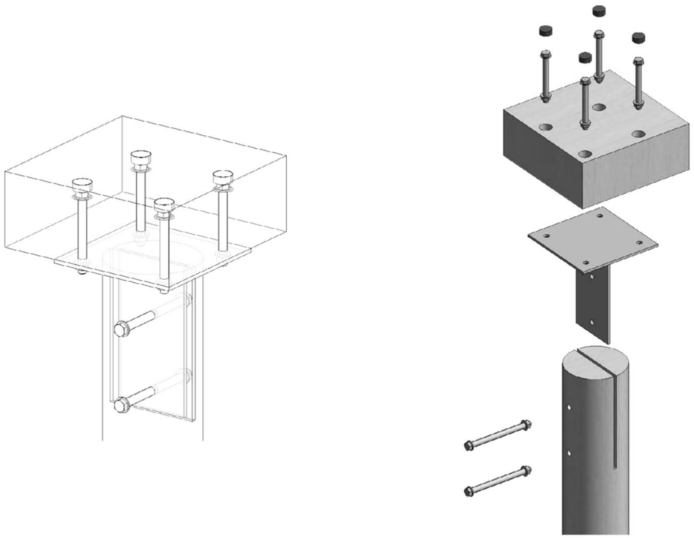


Figure 65: Foundation system design, Author's own

if the hillside is subject to erosion (Mackenzie).

A 200mm thick "punch pad" of concrete is first poured into the holes to provide a solid base for the timber post. Once the pole is dropped down into the hole, it must be held vertical with temporary props while additional concrete is poured down to surround the timber post and set (Structural materials roundwood applications 4). The concrete is poured until it reaches a level slightly higher than the ground plane. This ensures water will run off the concrete and does not pond (Mackenzie). Timber poles are naturally tapered and thus the posts are dropped into the holes with the wider diameter at the base, smaller diameter at the top to provide a solid vertical cantilever.

Once all the posts are in place they are cut to the correct height and a laser level is used to ensure they will provide a level building platform. Collaborating with a structural engineer, we devised a system for connecting the cross laminated timber (CLT) floor structure to the timber foundation poles. The top of each post would be cut through vertically to form a channel for the insertion of steel T plates. These plates could be slid up and down so that all T plates aligned to be perfectly level, at which point holes would be drilled through the timber post and steel plate for the bolts to be inserted. At the end of this process the site is ready for the CLT floor panels which span between these supports.

CLT

Cross Laminated Timber (CLT) is an engineered timber product which has been employed for a number years in Scandinavia and Germany. More recently, this technology is gaining popularity over other parts of Europe and in Canada. The manufacturing of CLT in New Zealand began in 2012 with the opening of the XLam factory in Nelson.

The material is constructed of glued dimensional lumber built up in layers, each layer with the grain laid perpendicular to the one below. This process creates a material which is strong in both directions and capable of forming the main structural system within a building. From an engineering perspective, it can be considered to have similar properties to precast concrete panels, yet it has added value being lighter.

CLT panels were employed in my designs due to the numerous benefits offered. Formed from timber harvested in sustainable forests, the panels act as a carbon bank and demonstrate superior seismic resistance. This system offers great design flexibility, as the profile of planar panels can be cut to any shape desired and still retain structural strength. CNC technology allows openings for doors, windows and services to be accurately cut quickly, and with ease. Individual panels are manufactured with all required holes grooves and edge details reducing onsite construction time.

XLam NZ ltd

XLam New Zealand Ltd's website provides an extensive resource of information on CLT construction for designers planning to implement CLT. There are three key documents available from the site, the *XLam Building Envelope Guide*, the *XLam Design Guide* and the *XLam Panel Assembly document* (XLam). The Building Envelope Guide provides standard construction details which formed a basis for my detailed construction design. The details from this guide which were of particular relevance to my desired construction system are included within the appendix.

Detail BE 1.5 illustrated the basic principles for my facade design. One issue with a vertical timber rain-screen lies with the horizontal battens behind the slats. As water can penetrate through the gaps between the slats, it is inclined to pool on the horizontal supporting battens behind, a potential watertight and decaying issue. Detail BE 1.5 illustrates that by forming an angle on the top of the battens, water can run away from the wall and off the battens without pooling. The battens will require very long, substantial screws to tie the rain-screen back into the CLT panels as noted on the drawing. Behind the battens, a water proof membrane would be required in place of the water resistant layer marked, due to the permeability of the timber slats.

I chose to implement detail BE 6.7, acoustic floor, not only to reduce the sound of impact heard between floors from foot traffic, but also for the additional benefit of a suspended floor space. As my design intention required the ceiling and walls to be exposed CLT structure with an architectural grade finish, a suspended floor would provide space for cables and plumbing.

The *XLam Design Guide* contains the specifications for this product. I used the span tables within the document to determine the required thickness of the panels which range from 60mm-200mm (Xlam 5). XLam offer both Radiata Pine and Douglas Fir options, however, I have selected Radiata Pine because there is less expansion and contraction between the boards with humidity fluctuations, and thus the interior finish will be less compromised (Xlam 5). Douglas Fir is more resilient to the elements, but as the CLT panels will be

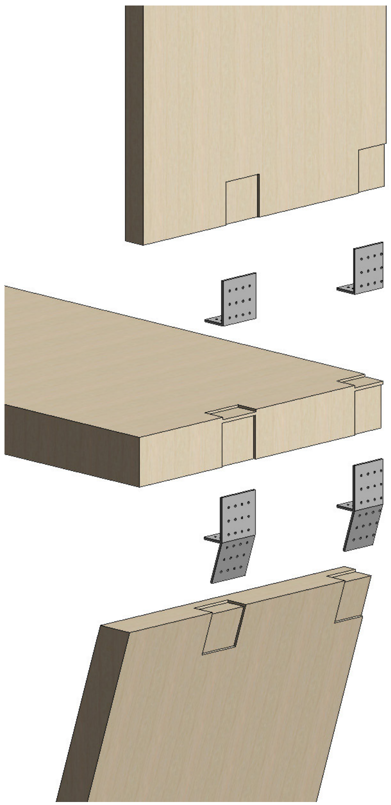


Figure 66: Testing fastening system (concept), Author's own

thoroughly protected from external moisture, selecting Radiata Pine is a logical and economical choice.

The *XLam assembly guide* is a document of details illustrating how to form strong structural connections between the CLT elements, and excludes all other layers within the construction system. Here, the appropriate position of coach screws, engineered wood screws and metal angle cleats are illustrated.

The size and position of these elements is to be specified by the structural engineer.

These details show the metal angle cleats installed on the interior, at the junction between the wall and floor. As previously mentioned, it was my architectural intent to present an architectural grade finish of the CLT structure on the interior faces of the walls and ceilings. The metal angle cleats with coach screws presented an architectural detailing issue, compromising a clean, minimal interior finish. I began drafting possible design solutions which positioned the metal cleats on the exterior face of the CLT panels, and rebated them into the panels resulting in a flush surface. Detail PA 1.3 evidenced the practice of rebating metal angles into the CLT structure.

While this was an ideal solution from an aesthetic perspective, it could prove impractical. To access the exterior of the CLT panels to screw the metal angles to the CLT, a scaffold would be required. However, to install metal angle cleats on the interior corners, the CLT floors provide the working platform. A scaffold would be required, either way, for the installation of the façade system, but this could be installed after all the panels were craned into place and thus not disrupt the panel installation process. Once the CLT floor and roof panels are placed, scaffolding is cantilevered from floors and walls on sloped sites because this method represents substantial economy (Xlam). The metal angle cleats therefore had to be installed prior to the installation of the scaffold, and therefore could not rely upon a scaffold for installation.

The second design solution was to rebate the metal angles into the CLT panels on the interior of the building. They would be rebated into the panels substantially so that a veneer of timber could be inserted into the rebate, covering the metal construction and maintaining a clean interior aesthetic.

Connections

It is paramount the connections between CLT panels be considered as these also have a great impact on the interior finish/aesthetic. XLam provide special self-drilling screws suitable for use with CLT. Available in lengths up to 600mm and diameters up to 12mm, screws with washers are recommended for connecting the main structure, while countersunk wood screws may be used at half lap panel joints (Xlam). Holes may be pre-drilled – a pilot hole of 80% of the screw diameter should be used (Xlam). The sizing and spacing of screws is determined by the structural engineer, however the aesthetic appearance is naturally the responsibility of the architect. I proposed holes be routered to a depth of 10mm, then pre-drilling to occur so that the screws can be concealed by wooden dowels, a veneer for the screw to conceal it. Larger screws which are fewer in number are therefore preferable to multiple screws to minimise excessive routering. Because the holes are machined, they will form a beautiful pattern of round wooden dowels in the wall expressing the construction while maintaining a clean finish.

KLH

KLH is Krueu Lagen Holz which translated into English means cross-laminated solid timber. Founded in Germany, the company [KLH Massivholz GmbH] is the leading manufacturer of large-format glued timber elements, which meanwhile are used worldwide under the brand name of KLH (www.klh.at/en/company/facts.html). On their website, a number of component catalogs can be accessed.

I studied the details provided in the *Component catalogue for building your own home* and the *Component catalogue for cross laminated timber structures,* as they demonstrated greater consideration for thermal performance. The following page is one such detail extracted from the *Building your own home catalogue*. I decided upon XPS insulation, as a higher thermal performance is reached for the respective thickness. Note that by using two layers of insulation, the first with insulation panels running vertically and the second with panels running horizontally, thermal bridging is minimised through the timber laths. Unlike the XLam details, the KLH ones feature taping over the joints for additional thermal performance.

With prefabrication of the façade construction, KLH recommends the subsequent installation of insulation in the joint area (KLH Building your own home 4). This implies that panels can potentially be delivered to site with the insulation already intact on the walls, particularly as they are craned from the top face so they hang vertically, and thus the insulation will not be an issue for lifting eye placement. XPS is has a very high compression strength so is unlikely to be effected by great loads stacked on top of it during transportation.

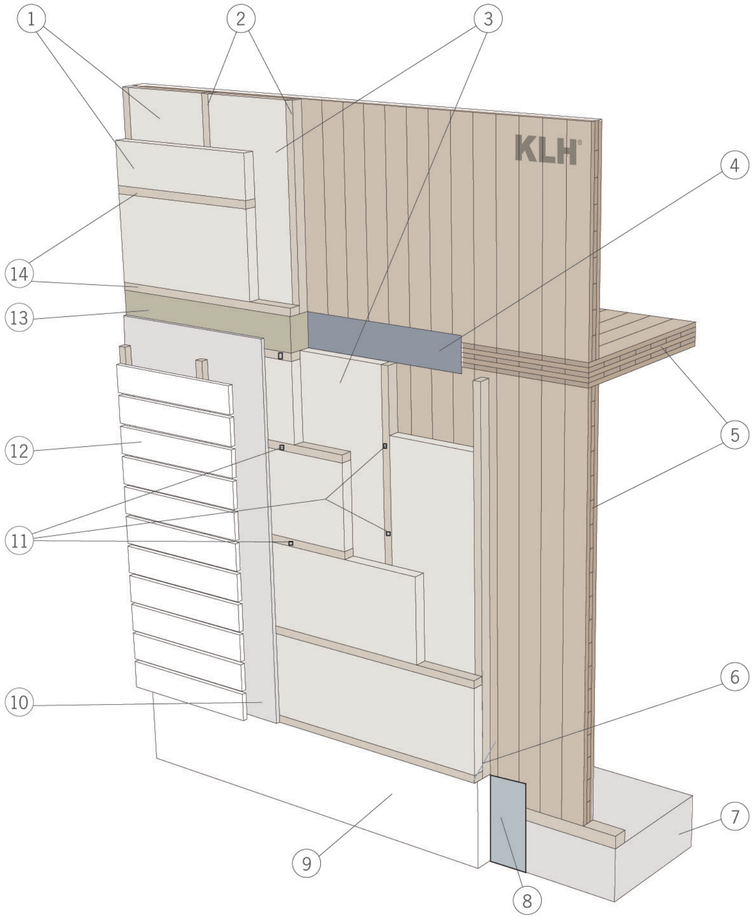


Figure 67: External wall structure with wood cladding - KLH

1. 2-layer insulation panel construction is recommended to avoid negative effects caused by possible joints
2. E.g. vertical interior laths if the rear ventilation laths run vertically
3. Insulation material of choice - in case of high fire protection requirements we recommend rock wool. Otherwise also hemp, cellulose, soft fibre or similar are possible. Insulation panels can be soft - the cladding supports the load of the facade (permanent vertical loads, wind loads)
4. Taping of the joints in the ceiling area - depending on the size of the joints (wind-sheltered area)
5. KLH wall and ceiling elements depending on static requirement
6. For heavy facades insert screws at an angle - the facade should be statically proven (wind, facade weight)
7. Concrete foundation
8. Extend sealing over the horizontal joint
9. Base insulation according to the requirements - e.g. XPS insulation in the splash-water area
10. Windproof and water-repellent layer dependent on the design of the facade. The more open the facade the more important is this layer - with open joints take the UV resistance into account
11. Screw connections depending on the static requirement - watch for wind suction in the corner area
12. E.g. wood facade
13. With pre-fabrication of the facade construction we recommend the subsequent installation of the insulation in the joint area
14. Transverse laths as an intermediate structure

I modified the detail in Figure 67, increasing the width of the subsequent installation to enable easier access for electric drills. It is paramount one considers ease of installation and accessibility for connecting components from an installers point of view, as speed and accuracy both depend upon this.

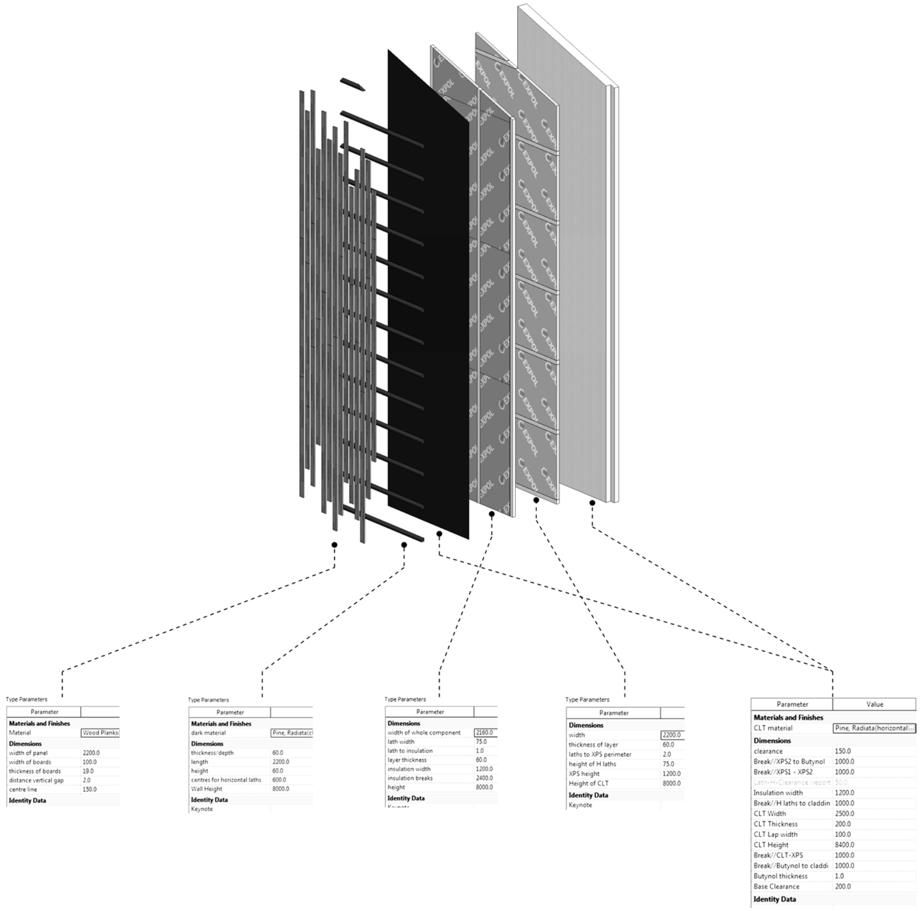


Figure 68: My fully parametric building skin design modified from KLH details
- Author's own

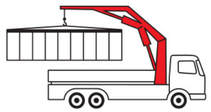


Figure 69: Palfinger truck mounted knuckle boom cranes - Gough Palfinger New Zealand

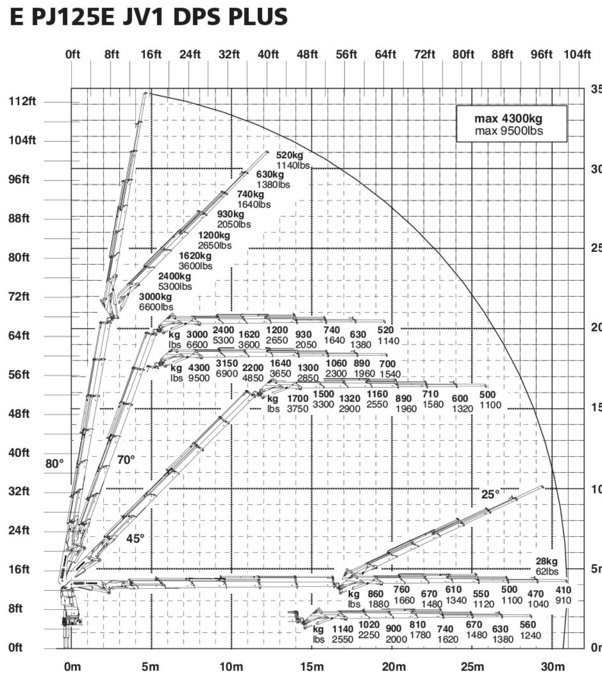


Figure 70: Palfinger knuckle boom crane capacity graph - Gough Palfinger New Zealand

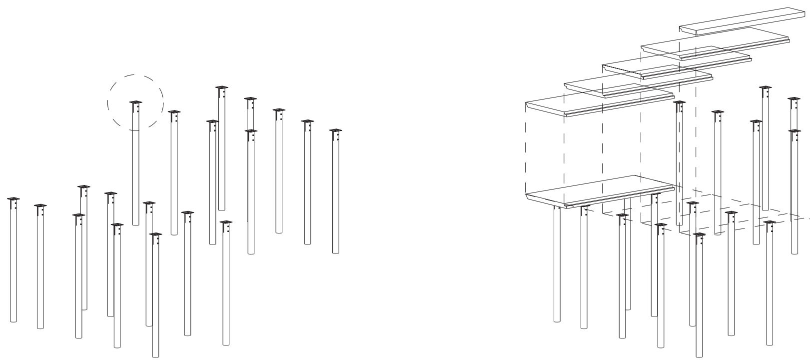
Transportation

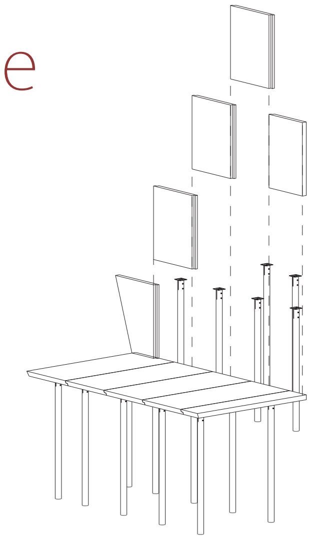
The panels are flat packed and delivered to site by truck, preferably a truck mounted knuckle boom crane. Naturally the panels must be stored on the truck in the order they are to be craned off, thus the floor panels of the ground floor are at the top of the pile and the roof panels are at the bottom. Floor panels are lifted via four large eyelets screwed into the top face while wall panels are craned from two eyelets at the top of the wall so that they hang vertical.

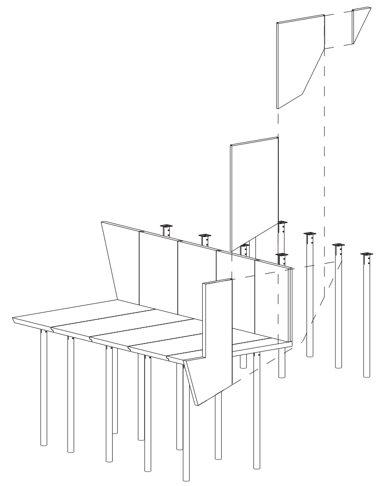
The New Zealand Transport Agency has set out a number of dimensional limits trucks and their load must conform to. This creates an envelope which the designer must work within regarding the size and shape of CLT panels. The maximum overall vehicle combination length is 19m; the width must not exceed 2.5m and the height no greater than 4.25m (NZTA).

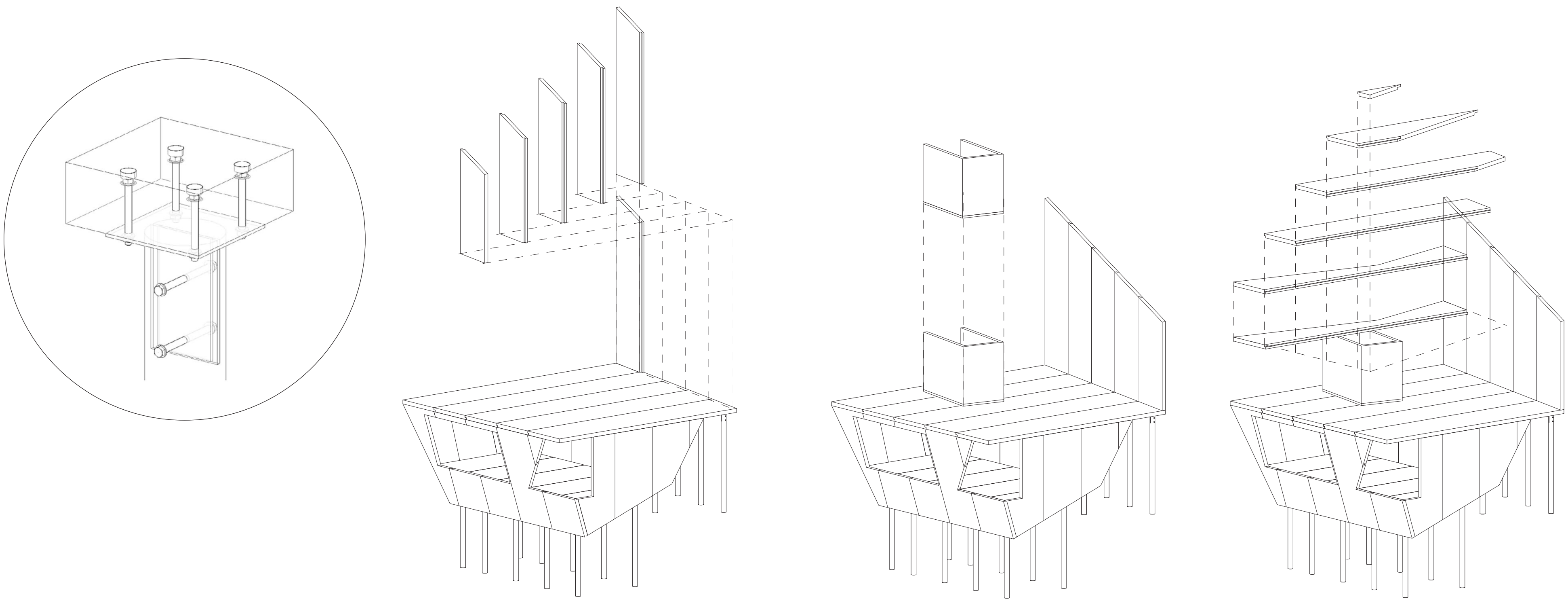
In my design, all the panels are 2.5m wide or less for transportation. The placing sequence is illustrated on the following page. It is planned around access and efficiency of movement. Half lap panel joints obviously require a predetermined direction of panel placement and which has been carefully thought out, as illustrated. The knuckle boom crane with hydrolic outreach will be adequate for all of the houses. In larger projects, a fly gib crane which gives a longer reach may be required (Xlam). To date, Xlam has utilised a Palfinger knuckle boom crane with a lifting capacity of 1,170 kg at 20.5 m (Xlam). Xlam has found the crane time for a floor or roof to average less than 1 hour per 100m2 of panel area placed (Xlam). The placing sequence works from the back corner of the site forward to the front, similar to laying a tongue and groove floor.

3.4. Construction Sequence









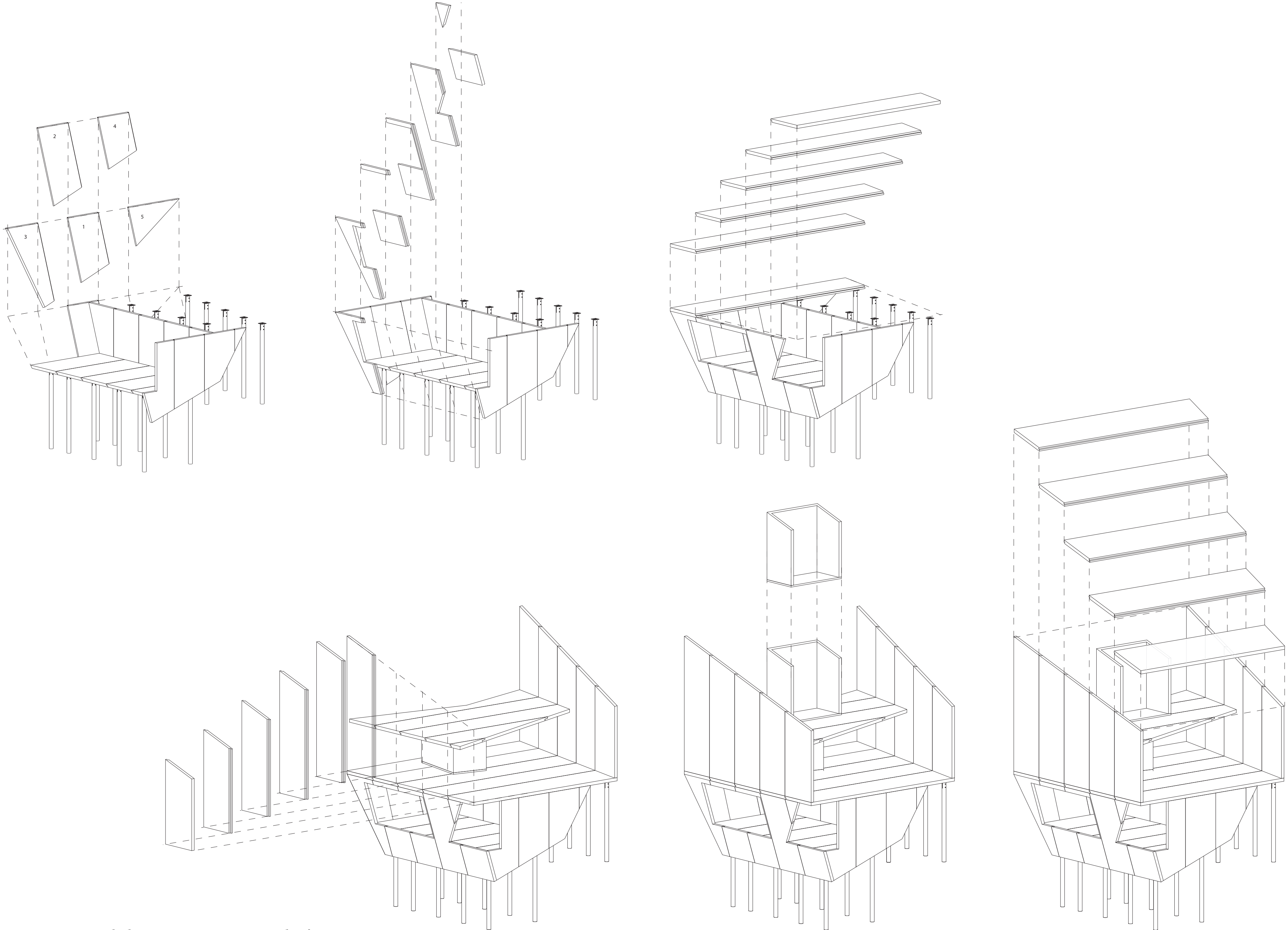


Figure 71: Panel placement sequence - Author’s own

Construction Sequence

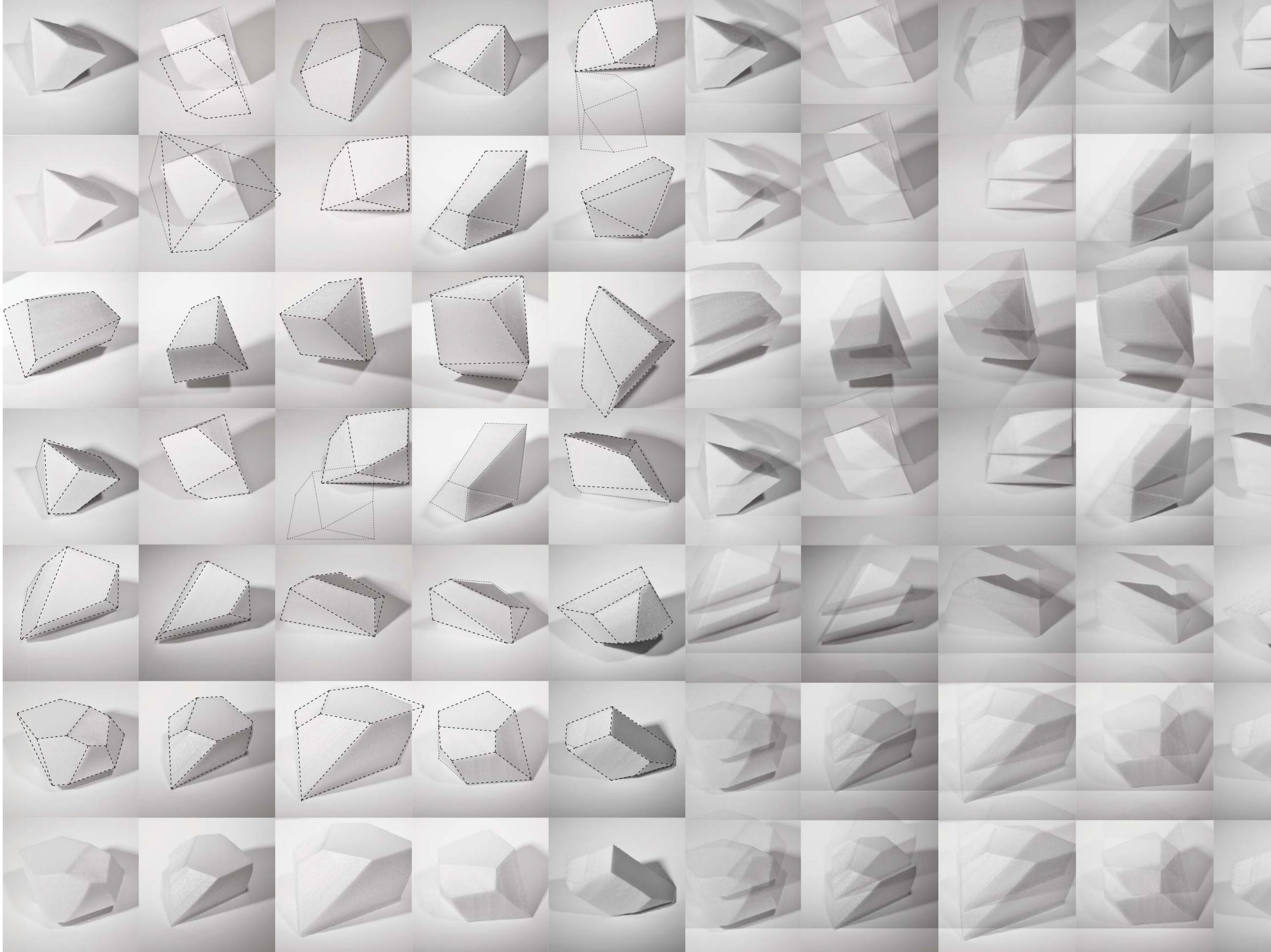
Following is the construction sequence as outlined in the diagram on the previous page.

- ∞ *Timber poles inserted into bored holes with concrete punch pad. Concrete poured into holes to secure poles in place.*
- ∞ *Poles cut to be level with one another and correct height above ground. Chanel cut into top of posts to insert steel T plates. Steel T plats secured with bolts.*
- ∞ *Ground floor panels craned into place with HiAb*
- ∞ *Internal ground floor walls and external ground floor walls craned into place (excluding front panels) and fixed with steel plates*
- ∞ *Stair section lifted into place and secured*
- ∞ *Front ground floor walls lifted into place*
- ∞ *First floor panels maneuvered onto structure and secured.*
- ∞ *Rear walls craned into place [secured and propped]*
- ∞ *Kitchen block (wrapped) craned in*
- ∞ *Internal walls craned in*
- ∞ *Bathroom block lifted in place and secured*
- ∞ *Stair section lifted into place and secured*
- ∞ *Front panels installed and secured [with props]*

- ∞ *Mezzanine floor panels craned into place*
- ∞ *Bathroom block craned into place*
- ∞ *Internal walls craned in*
- ∞ *Window supporting structure installed*
- ∞ *Windows installed*
- ∞ *Roof structure craned into place*
- ∞ *External insulation panels installed underneath building*
- ∞ *External insulation panels attached to exterior*
- ∞ *Watertight membrane*
- ∞ *Flashings and down pipes installed*
- ∞ *External cladding attached*

4 Design Discussion

Figure 72: Concept models exploring the geometry of faceted forms - Author's own



4.1. Site

The site which the third design study is based on is within Waitaha Cove along Queens Drive, west of Lyall Bay, Wellington.

The site faces south to east as sections follow the curve of the hillside. Despite south facing sites being less desirable, this area was chosen specifically for its dramatic outlook. The hill side shelters the area from prevailing Northerlies but the houses will be exposed to Southerly winds.

The characteristics of the site which aided in the selection are as follows:

∞ The dramatic outlook of the rocky coastline facing onto the rough Cook straight beyond offers the celebration of the NZ landscape

∞ The hillside is steep posing a challenge – successful design will demonstrate how difficult sites can be utilised by employing prefabrication

∞ This site can be mitigated with architecture

∞ Existing foliage will aid the integration of the houses into the landscape

∞ Indirect lighting is desirable to achieve the intended atmosphere.

∞ Architecture and occupants to be immersed in the natural landscape.

∞ Soft lighting enters south facing windows similar to the lighting in Norway

Figure 73: Site [Waitaha Cove, Queens Drive, Wellington] - sourced from Google Maps prior to editing

Figure 74: Site in the context of Wellington
- retrieved from Google Maps

4.2. Urban Planning and Access

Each house has been arranged in a sequence which enables inter-dwelling privacy. The houses are rotated so that the windows look towards the view but not into neighbouring houses.

The structure of the first story and mezzanine floor are consistent throughout all designs while the ground floor panels are customised to fit the specific slope.

Comparable to the works of JVA discussed earlier which demonstrate worthy examples of tip toeing on the site; these five designs embody the same principle. However, there was an additional aim to prevent a prefabricated house design which raised the structure of the building up on stilts, divorcing the form from the topography as the slope becomes irrelevant to the building platform. These seemingly opposing principles were mitigated with the typology I implemented and transformed.

Figure 75: Site plan render

Figure 76 (opposite page): View looking southwest towards the cove

Figure 77: Site plan

Figure 78 (opposite page): Site plan detailing view scope from each house taking note of neighbor privacy and most interesting outlooks.

4.3. Planning

Figure 79: Diagram demonstrating house sitting slightly above ground to ensure natural water course unaffected by building - Author's own

How does the planning differ from flat site housing designs?

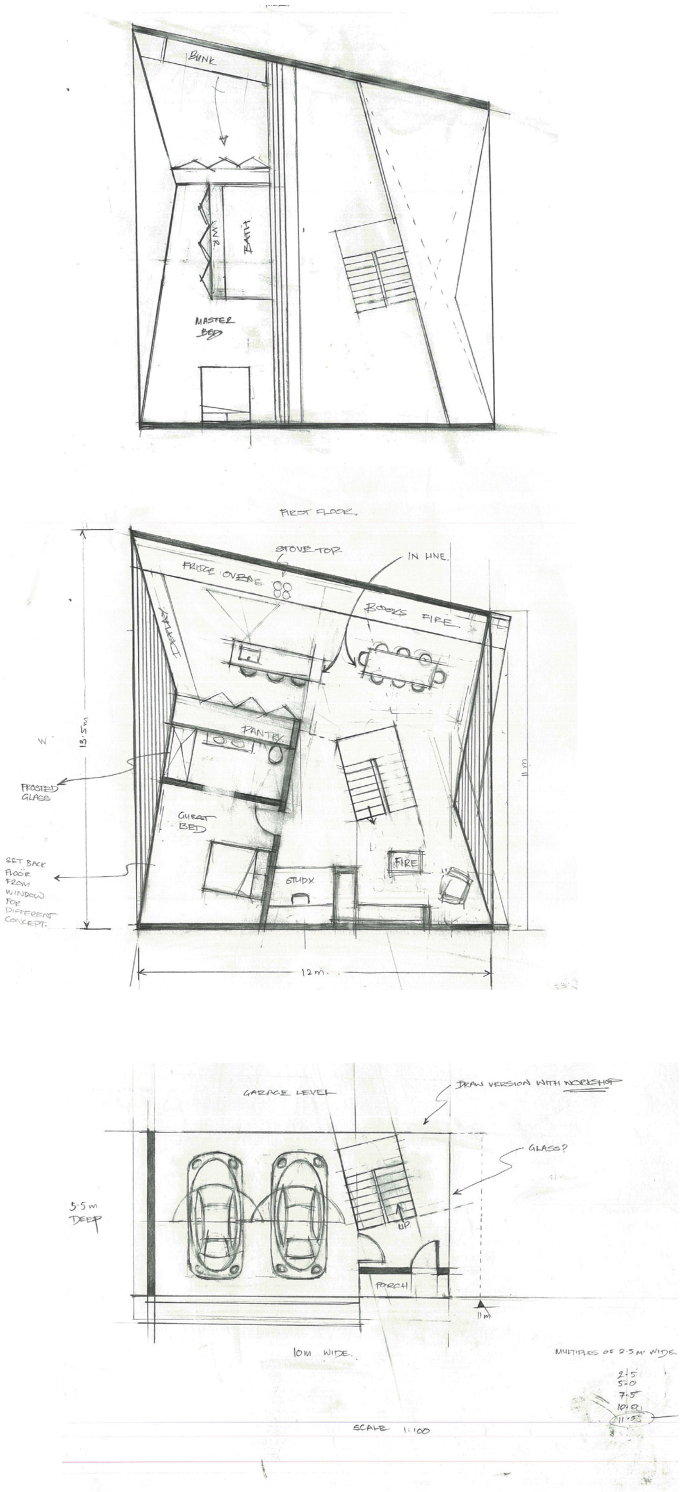
In most two storied houses on flat sites, one can observe how often each floor is propagated upwards replicating the floor area and following the floor plate boundary shape of the floor below. [Form is extruded upwards from the ground floor plate to create the overall mass] The ground floor plan here is narrower in the direction perpendicular to the slope, and then vastly increases in width on the floor above to step up the hillside. The placement of the garage must be uphill of the slope to work with the road as outlined by Arthur Levin (80).

While three storied houses are uncommon on flat sites, this is a regular occurrence on hill sites. The slope alters the perceived scale of the house, diminishing its apparent height so it does not tower like a house on a flat site might. An example of this is Hill House by Johnston Marklee & Associates. A three storied house on a hill site takes advantage of the view more so than a two storied house.

The plan illustrates a vertical progression from public to private. The entry space on the ground floor is the most public, leading up the stairs to reach the living area directly, from which the kitchen and dining branch off. The staircase continues upwards to reach the bedrooms, the most private area.

What is the logic behind the circulation?

By selecting a central core staircase it is not only economical in terms of space, but it simplifies the circulation. For a 3 storied house, a staircase core creates

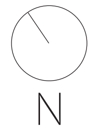


and unobstructed path and the shortest distance from the ground floor to the second story.

Using the half landing stair type as opposed to the straight flight, a smaller void is cut out of the floor plate, minimising the area the staircase covers. The landing divides the staircase into two; thereby reducing the quantity of treads in one flight making walking more comfortable by proving a rest mid-flight. This stair type is more adaptable to a number of different planning configurations.

The stair is a central sculptural element within the house, the folding wooden form which encases it weaving up the core of the home.

Figure 80: Sketch plans - Author's own



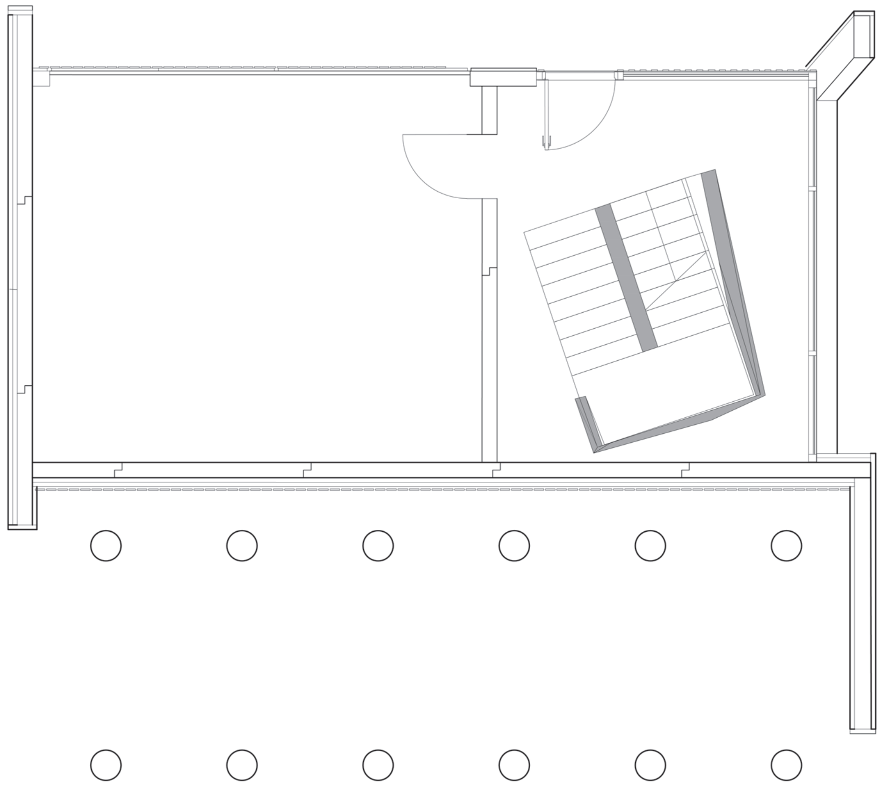


Figure 81: Example plan view of ground floor,
Scale 1:100 at A4
1:50 at A2

Figure 82: Example plan view of first floor,
Scale 1:100 at A4
1:50 at A2

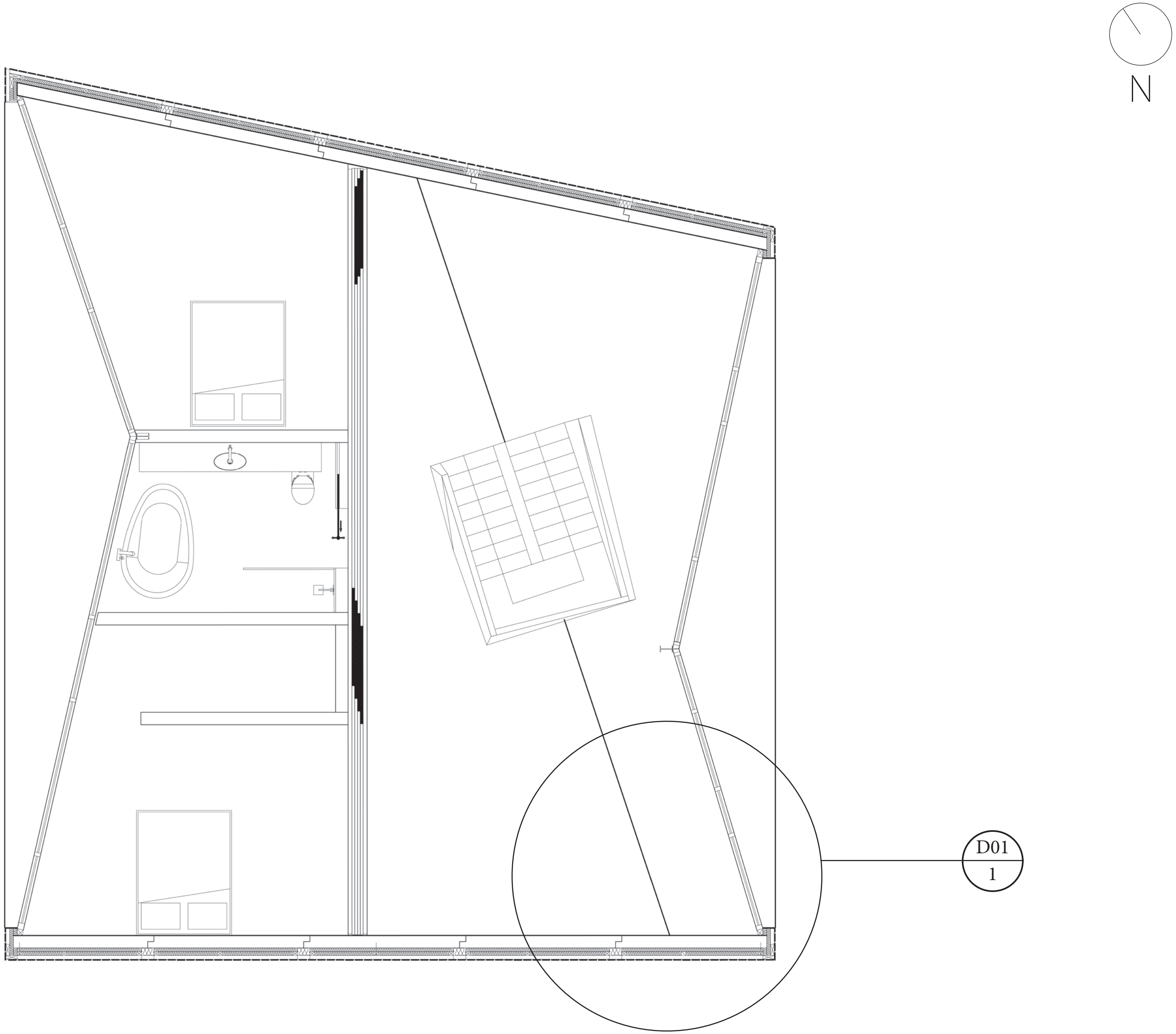


Figure 83: Example plan view of second floor,
Scale 1:100 at A4
1:50 at A2

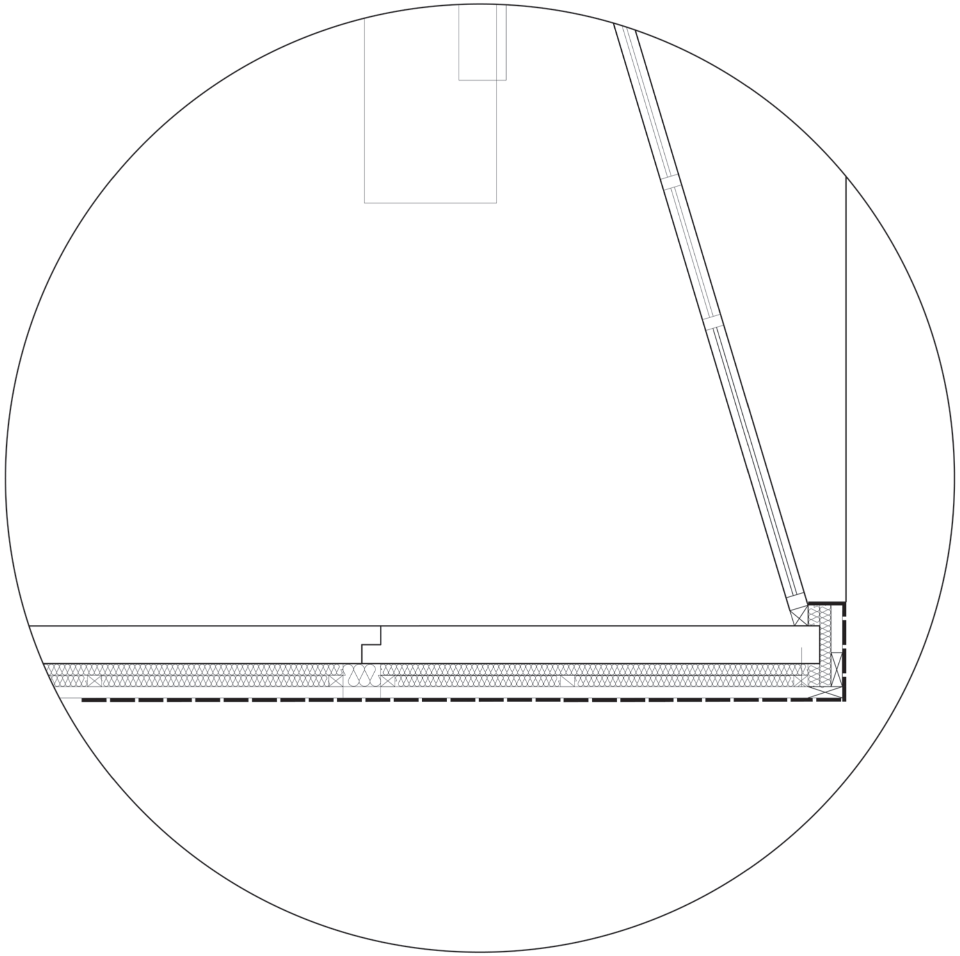


Figure 84 : Detail of wall construction D01 (plan),
Scale 1:40 at A4
1:20 at A2

House 1

1. entry
2. garage
3. kitchen
4. dining
5. living
6. bathroom
7. master bedroom
8. bedroom

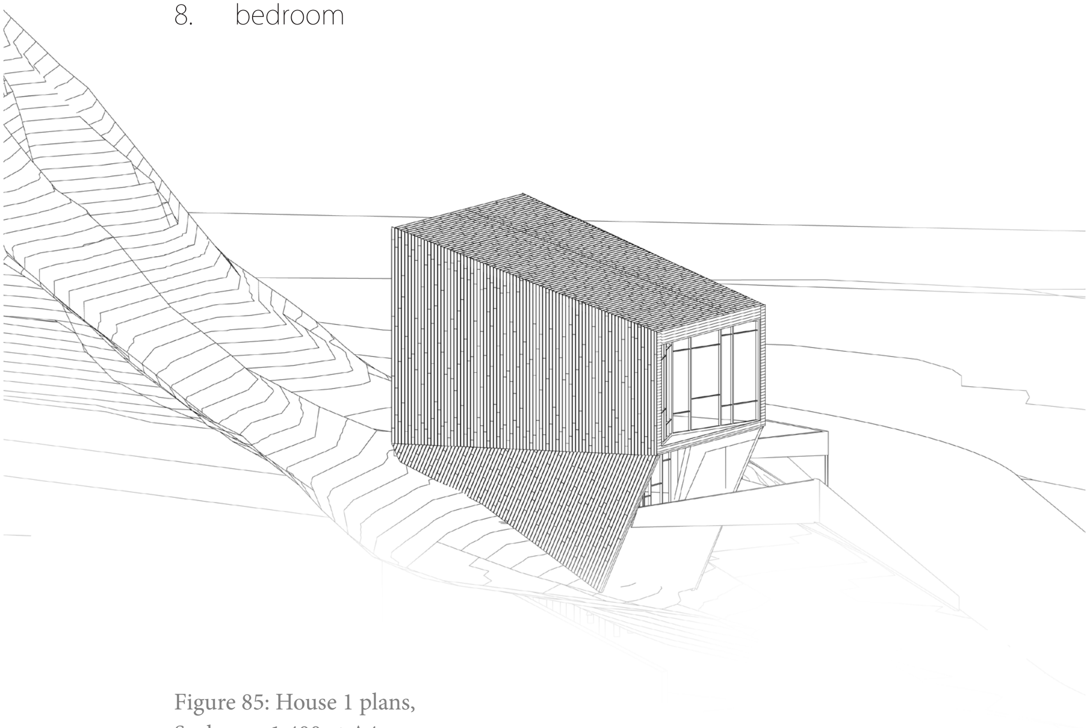
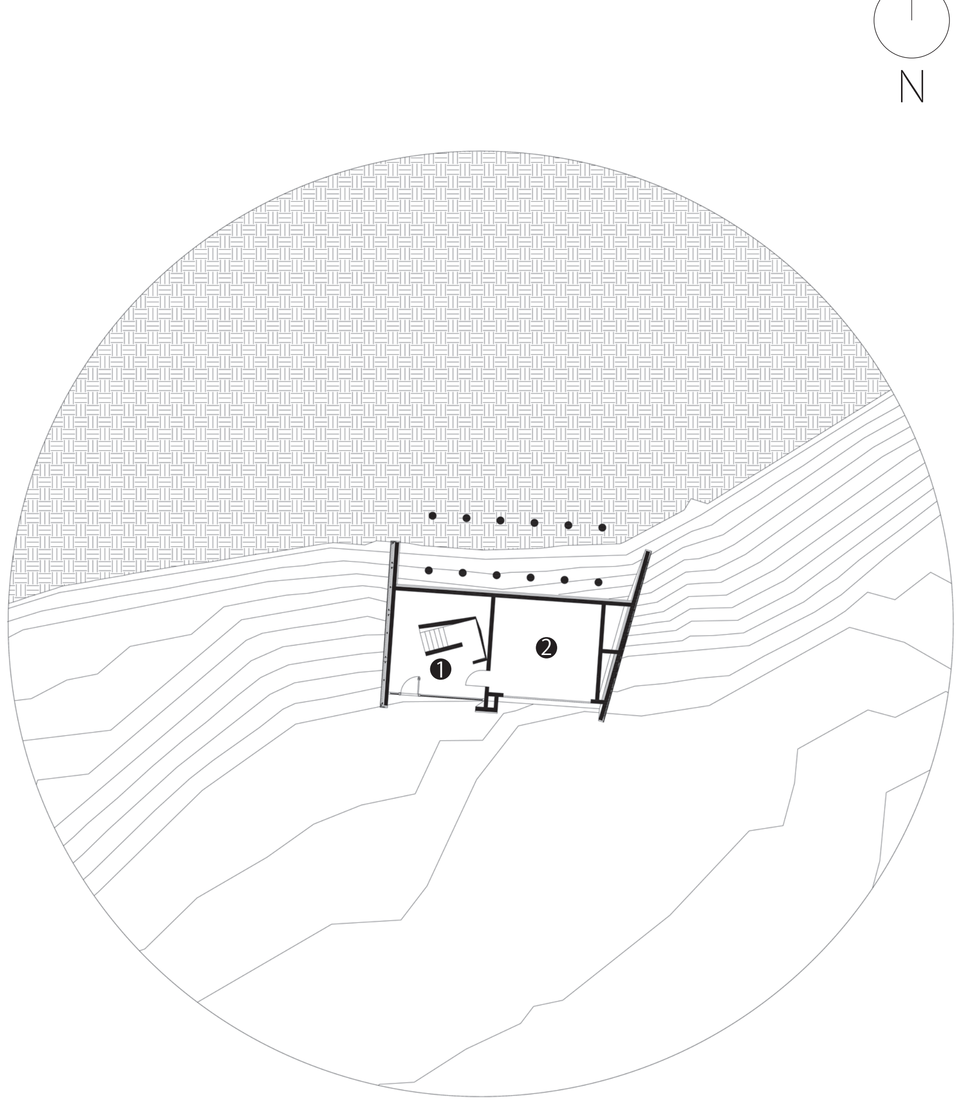
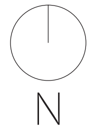


Figure 85: House 1 plans,
Scale: 1:400 at A4
1:200 at A2



GROUND FLOOR

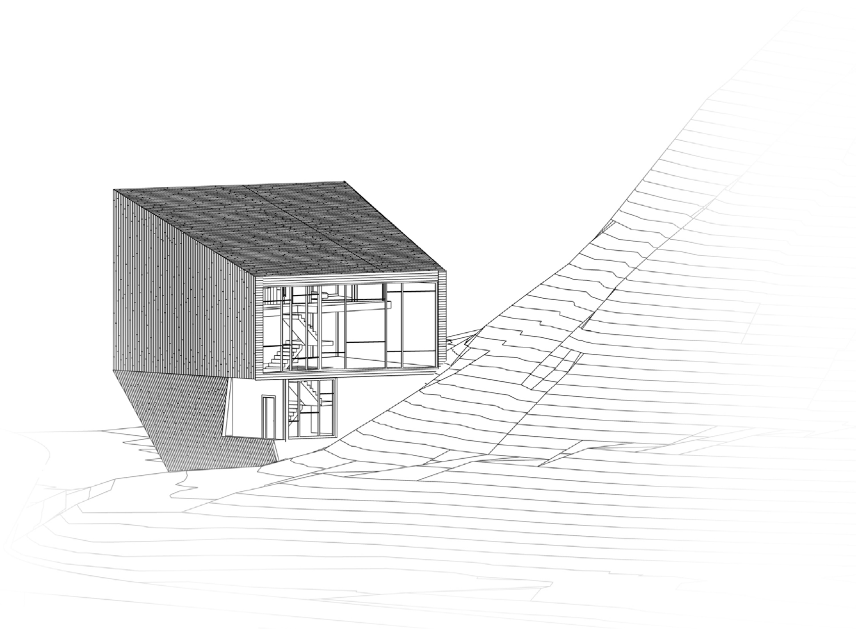


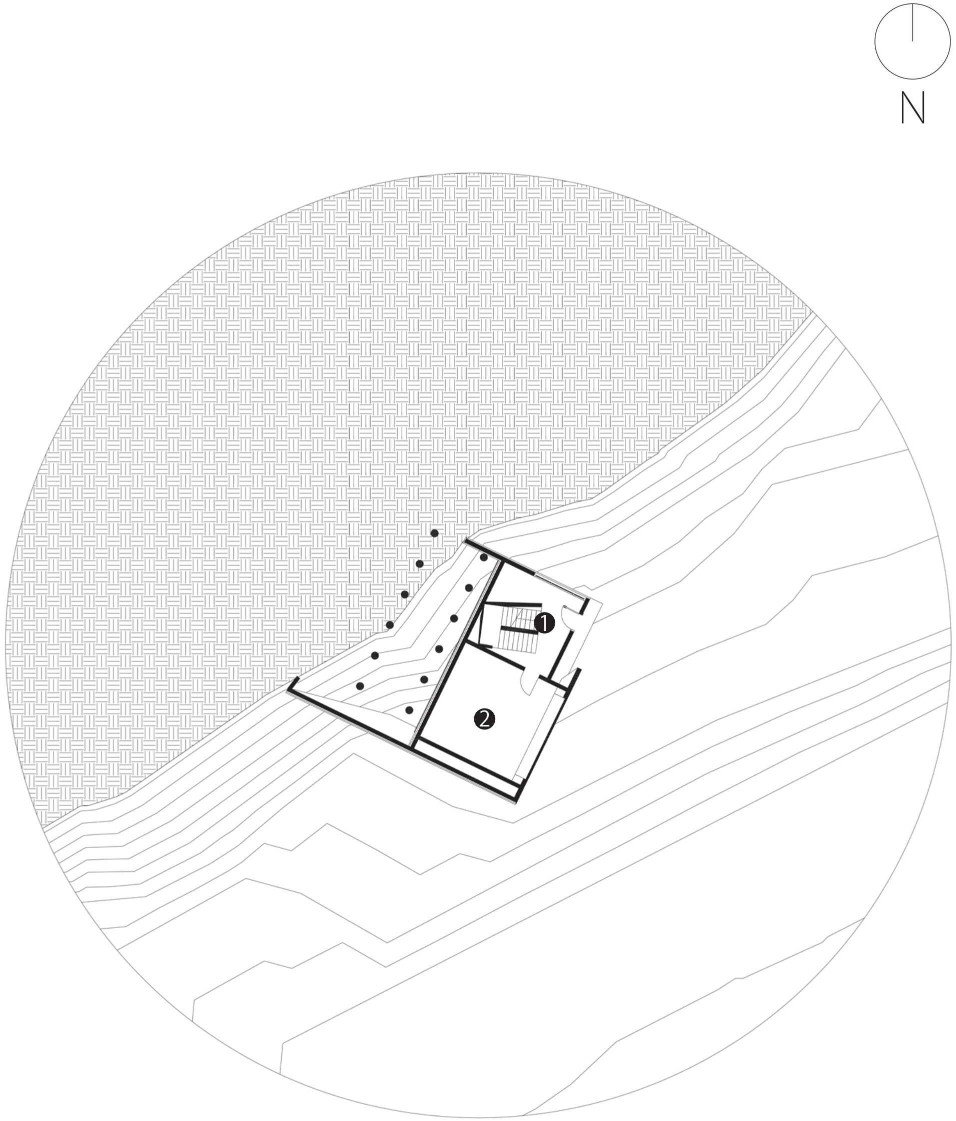
FIRST FLOOR

SECOND FLOOR

House 2

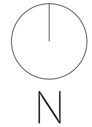
1. entry
2. garage
3. kitchen
4. dining
5. living
6. bathroom
7. master bedroom
8. bedroom
9. study

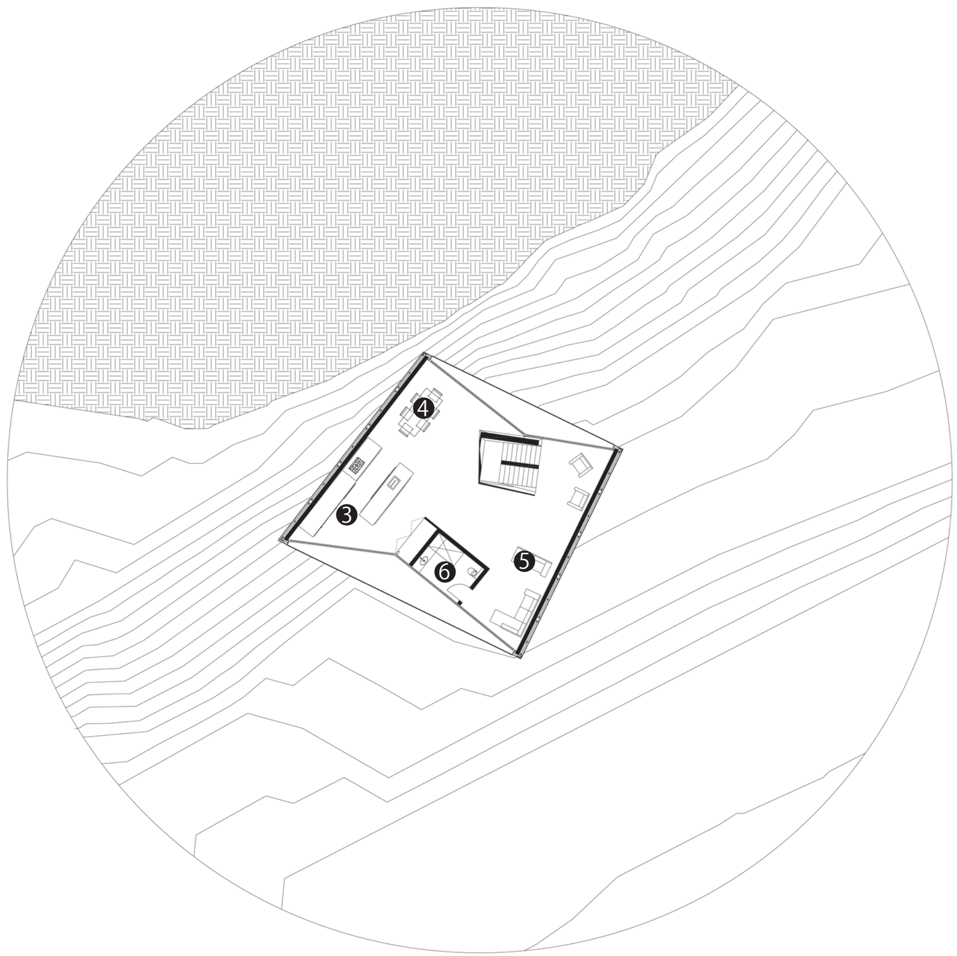




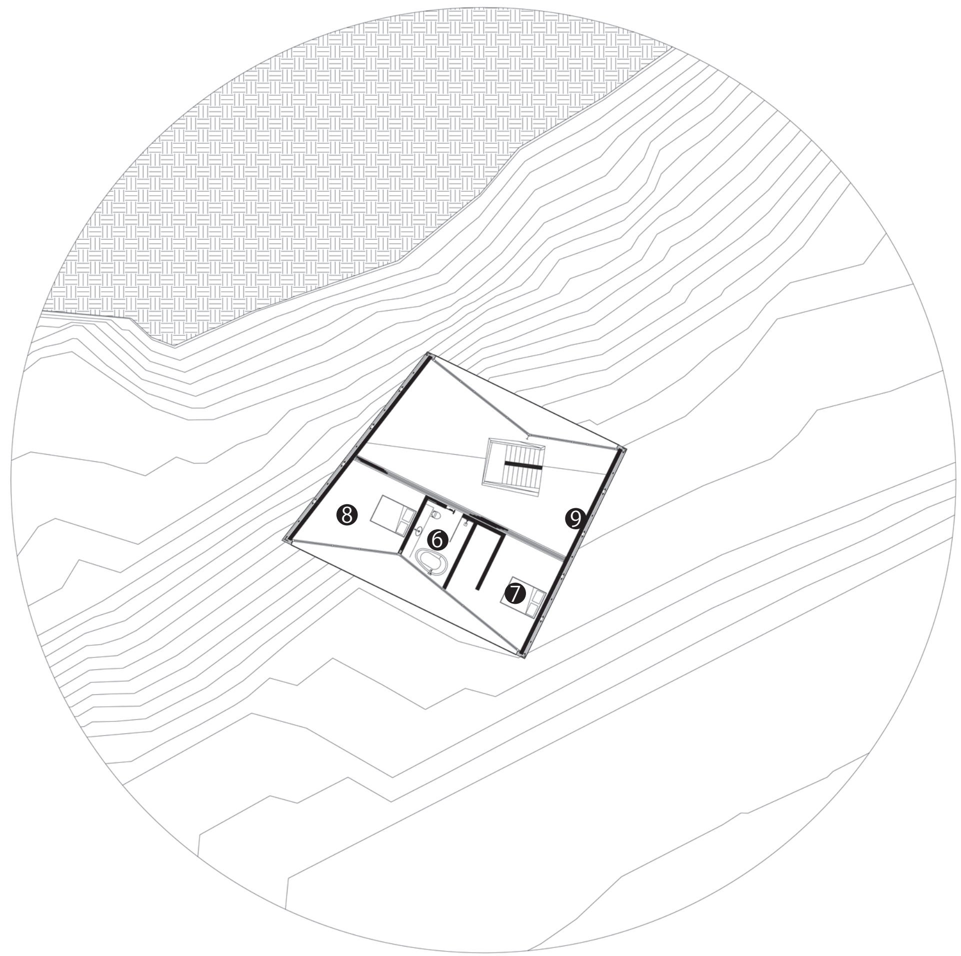
GROUND FLOOR

Figure 86: House 2 plans,
Scale: 1:400 at A4
1:200 at A2





FIRST FLOOR



SECOND FLOOR

House 3

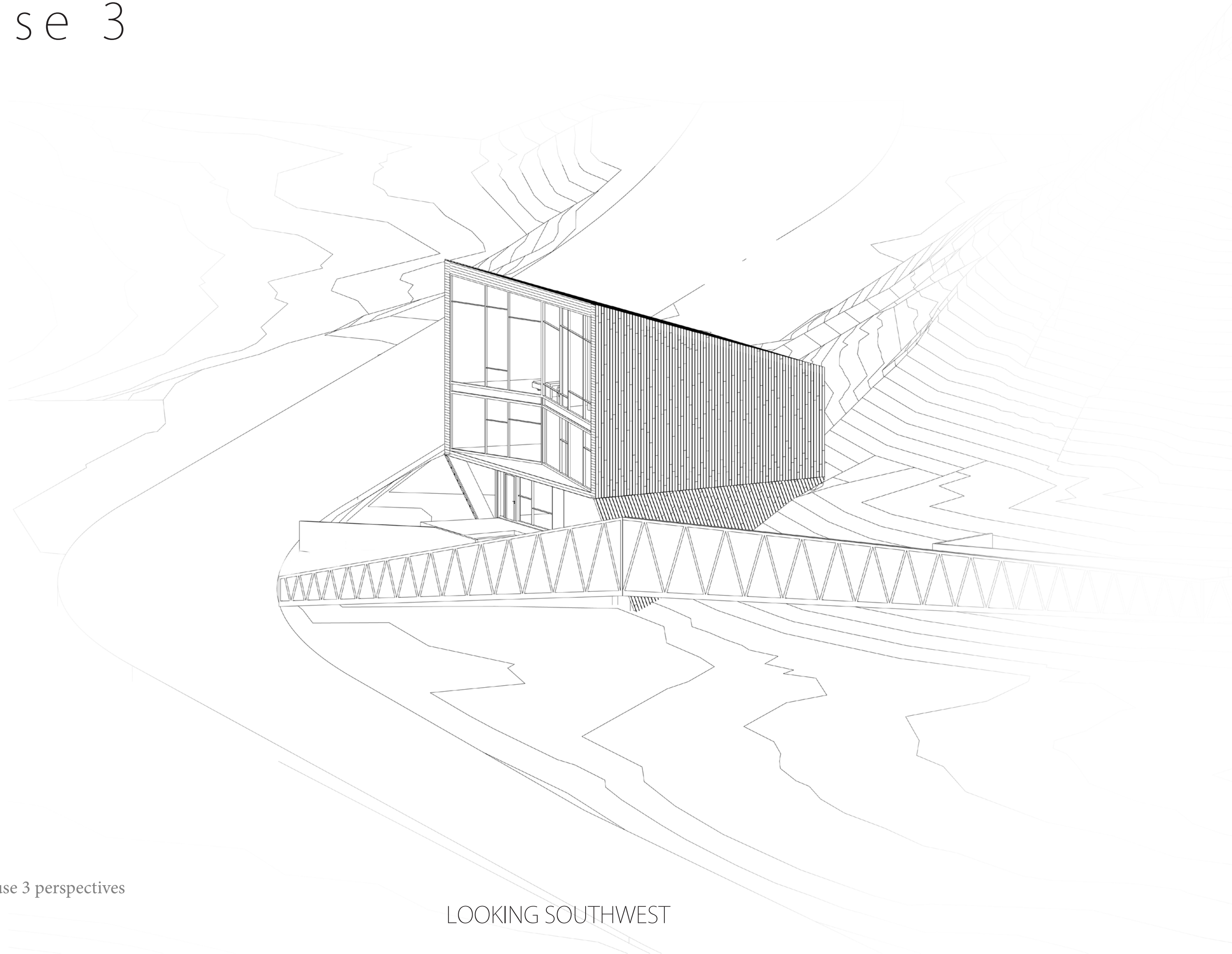
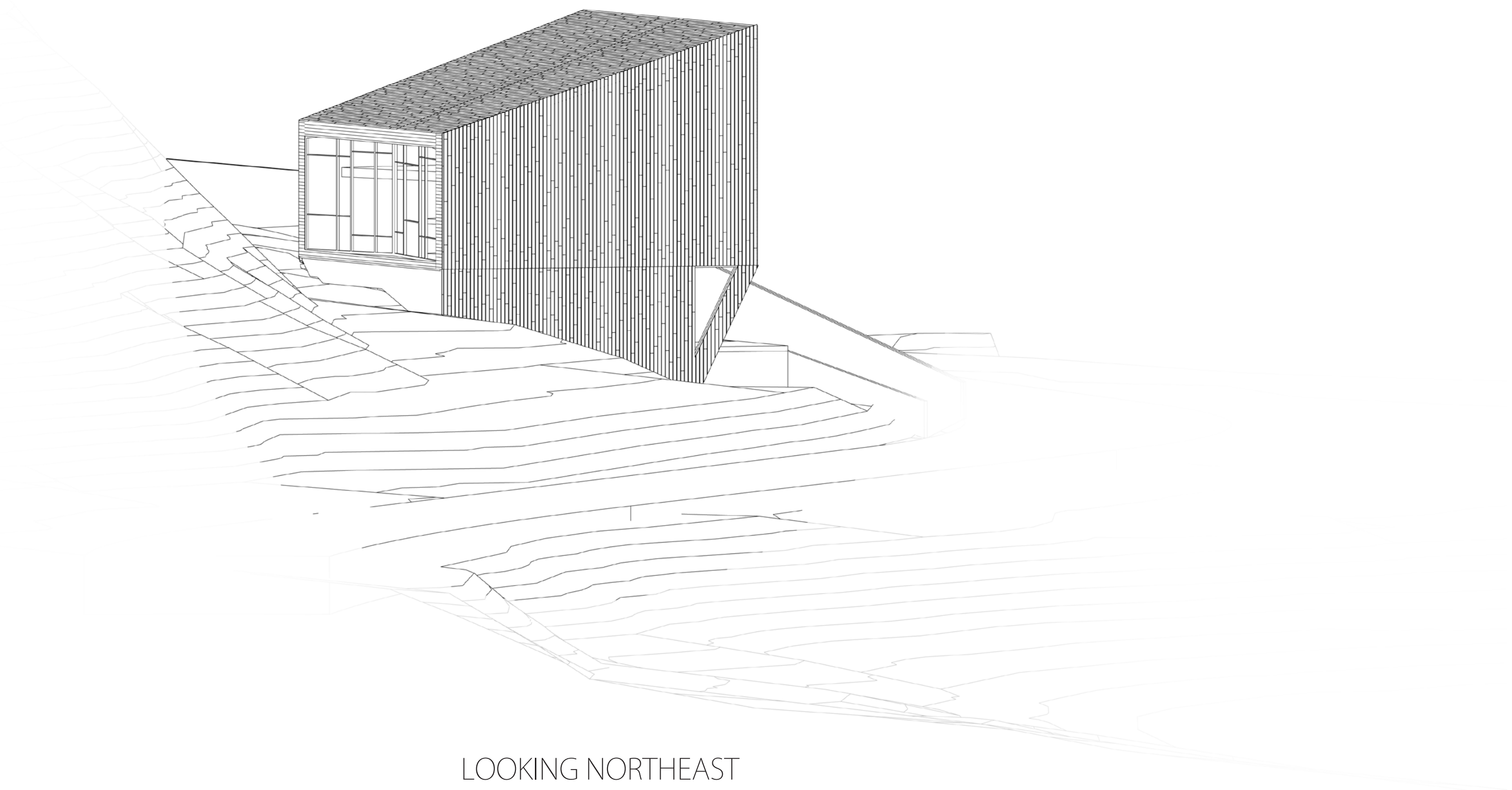


Figure 87: House 3 perspectives

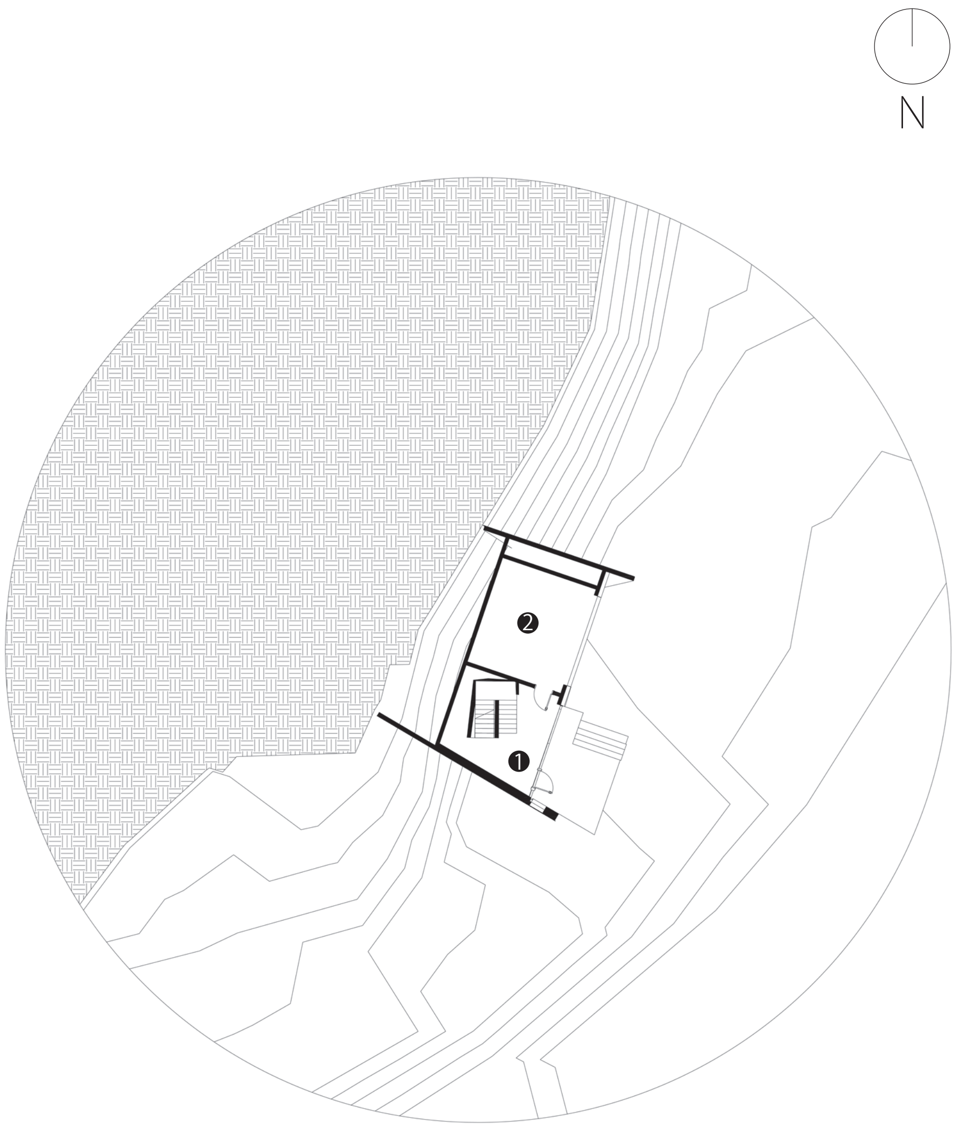
LOOKING SOUTHWEST



LOOKING NORTHEAST

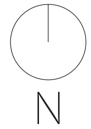
House 3

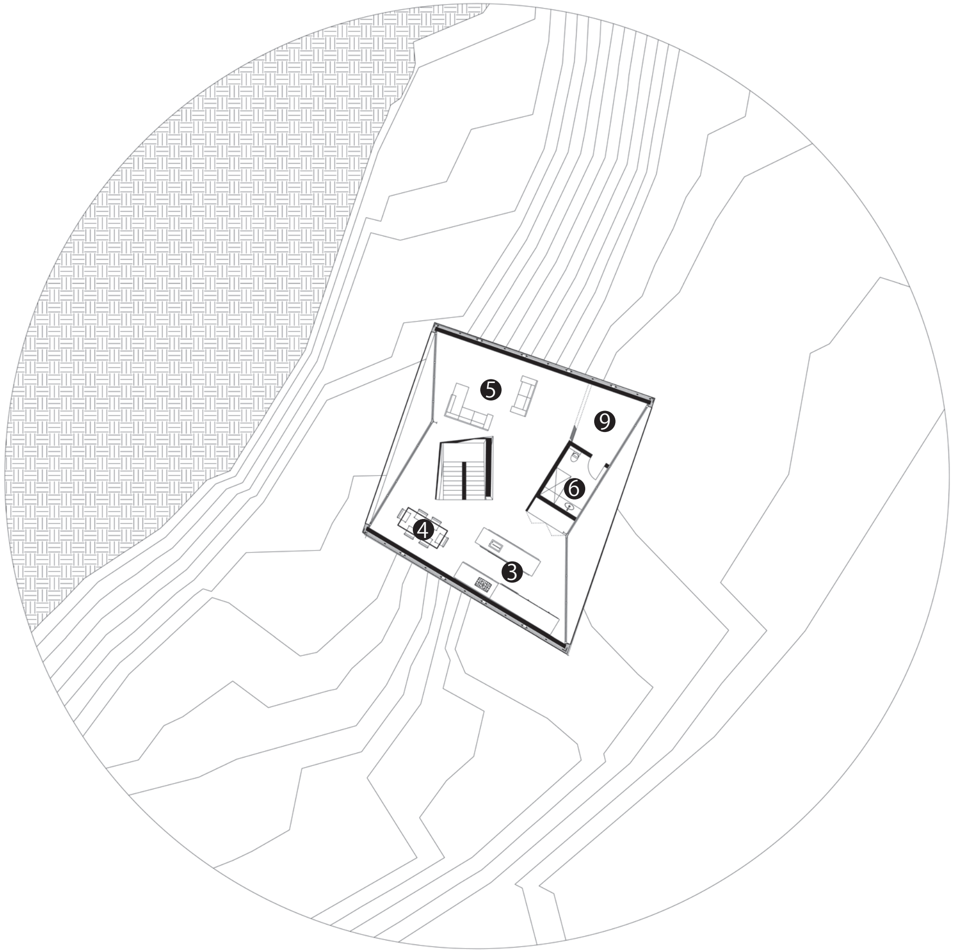
1. entry
2. garage
3. kitchen
4. dining
5. living
6. bathroom
7. master bedroom
8. bedroom
9. study



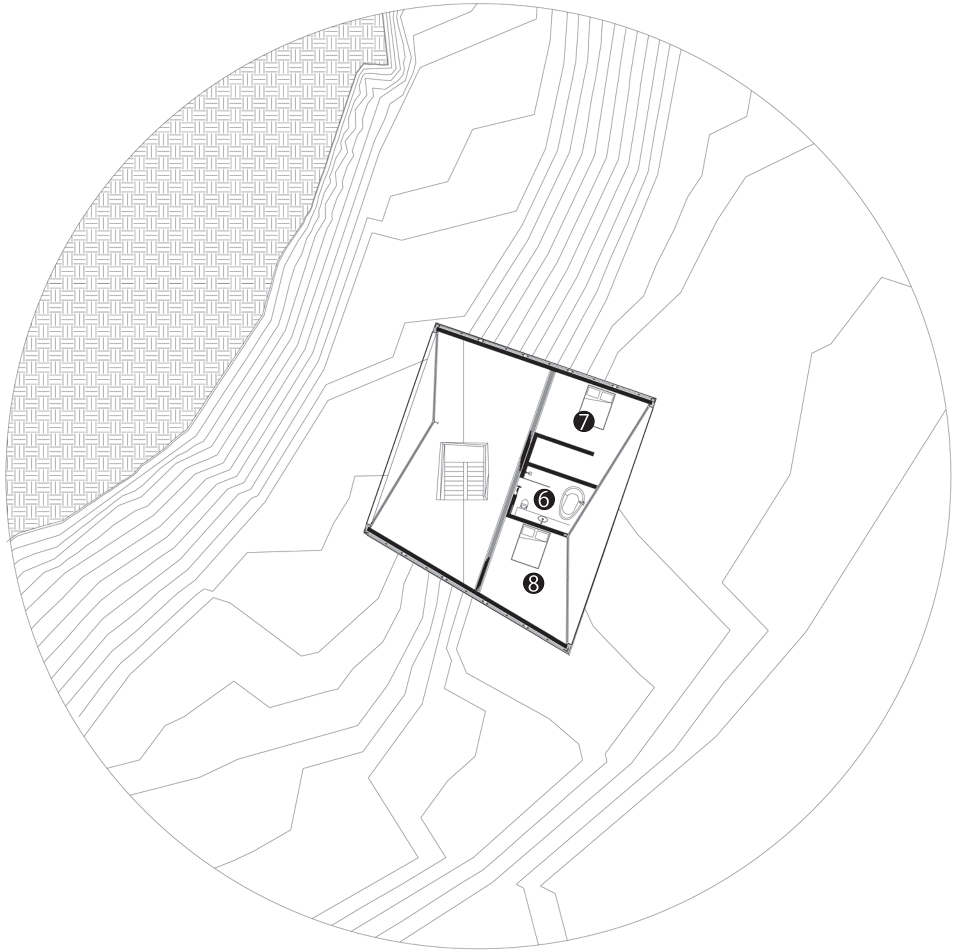
GROUND FLOOR

Figure 88: House 3 plans,
Scale: 1:400 at A4
1:200 at A2





FIRST FLOOR



SECOND FLOOR

House 4

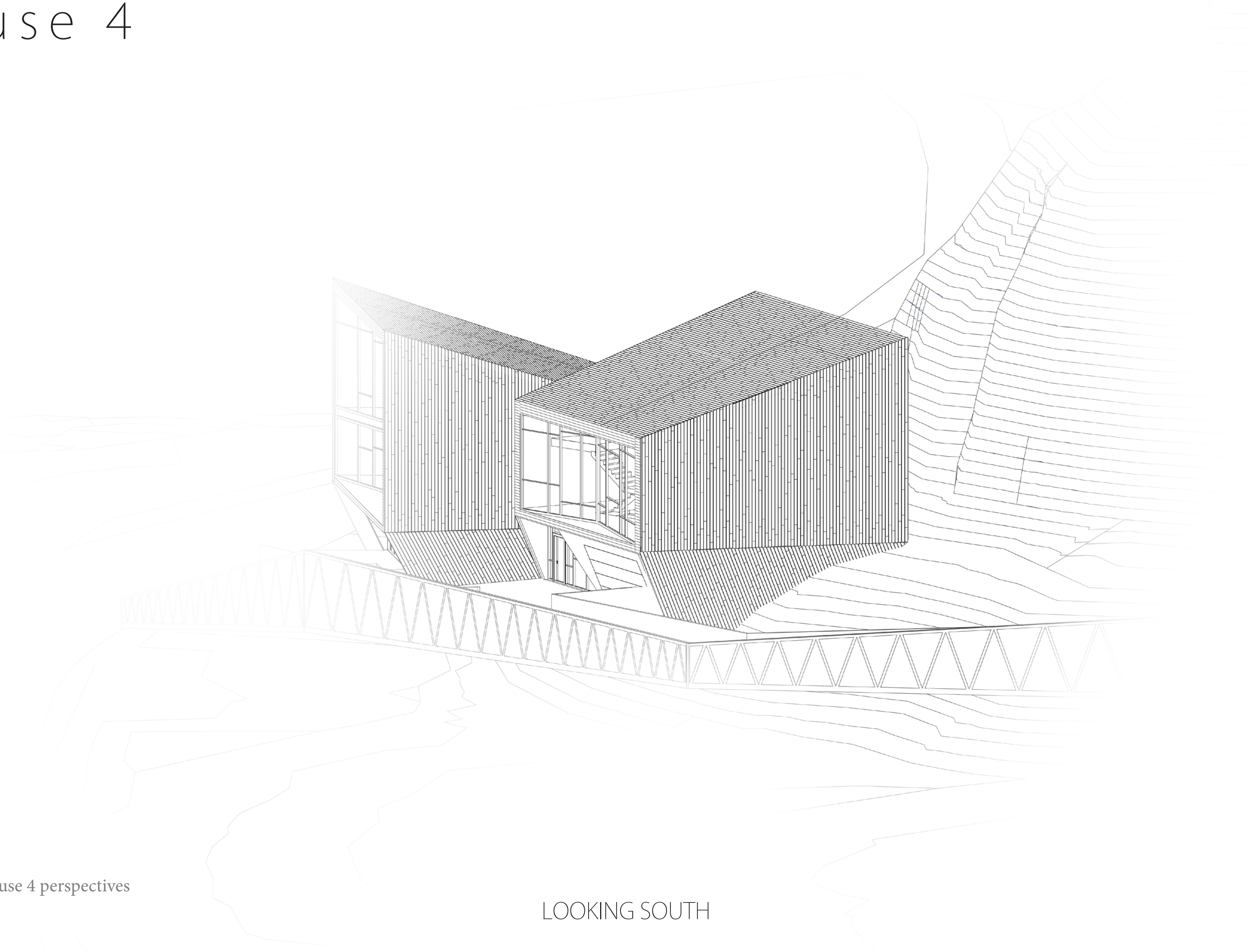
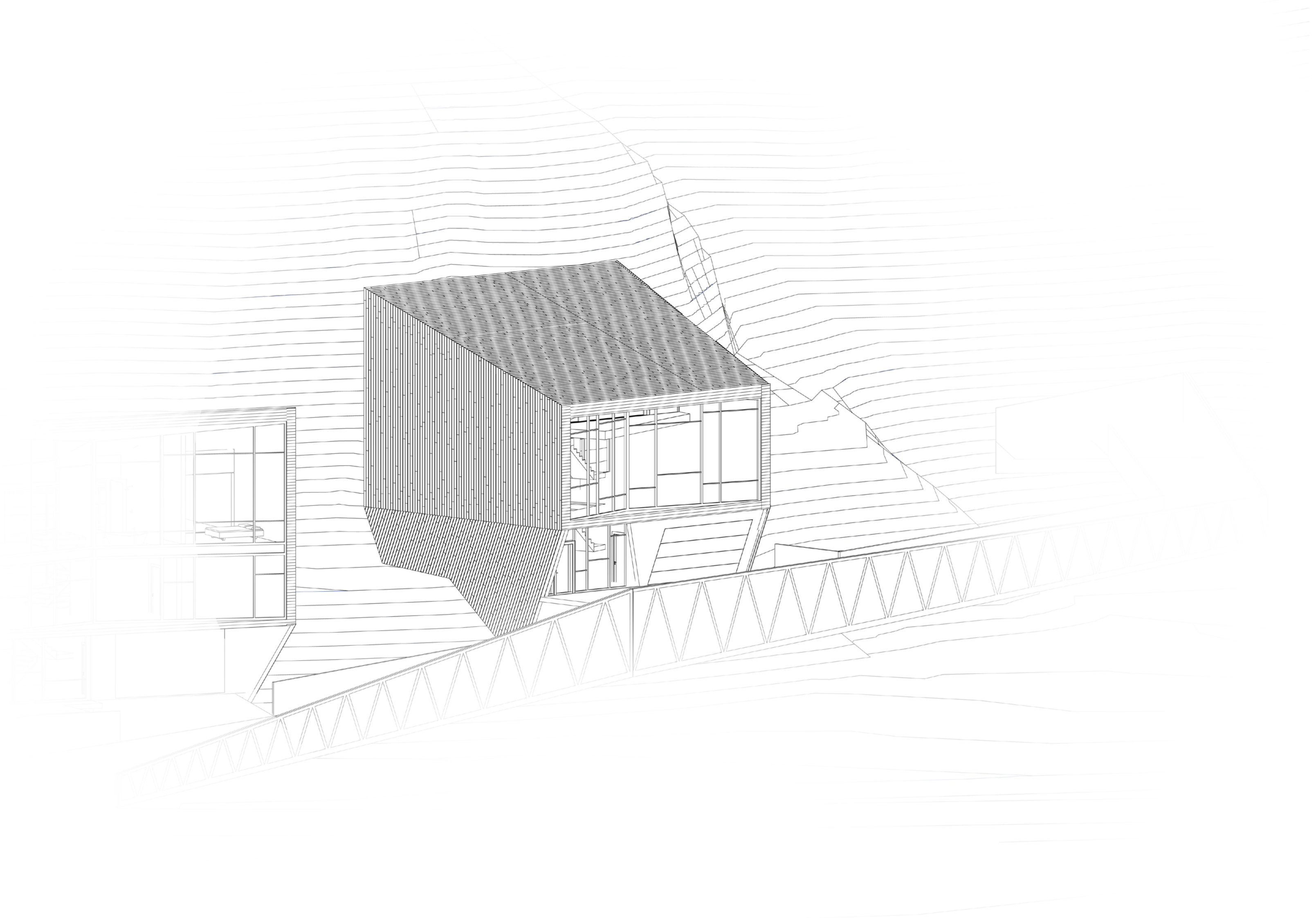


Figure 89: House 4 perspectives

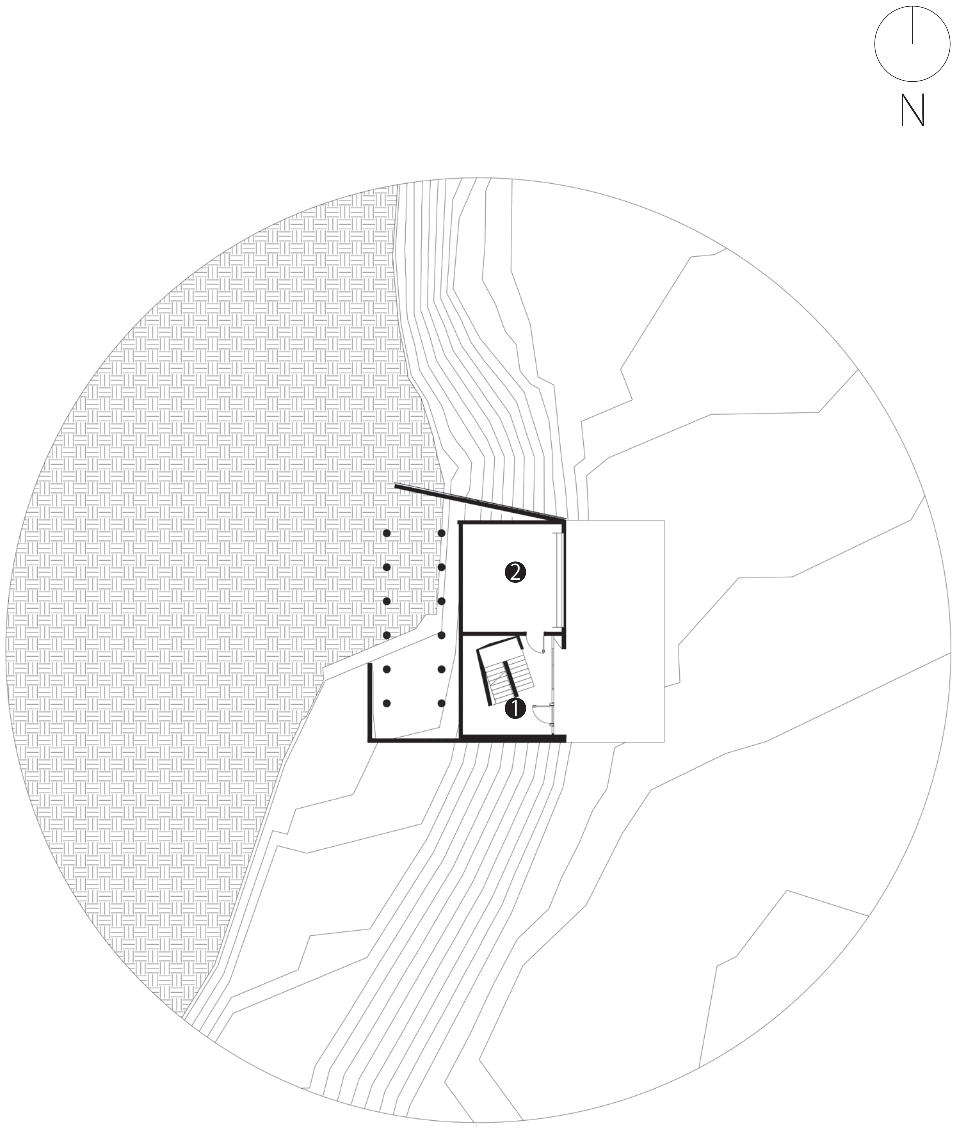
LOOKING SOUTH



LOOKING NORTHEAST

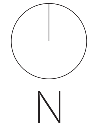
House 4

1. entry
2. garage
3. kitchen
4. dining
5. living
6. bathroom
7. master bedroom
8. bedroom



GROUND FLOOR

Figure 90: House 4 plans,
Scale: 1:400 at A4
1:200 at A2



FIRST FLOOR

SECOND FLOOR

House 5

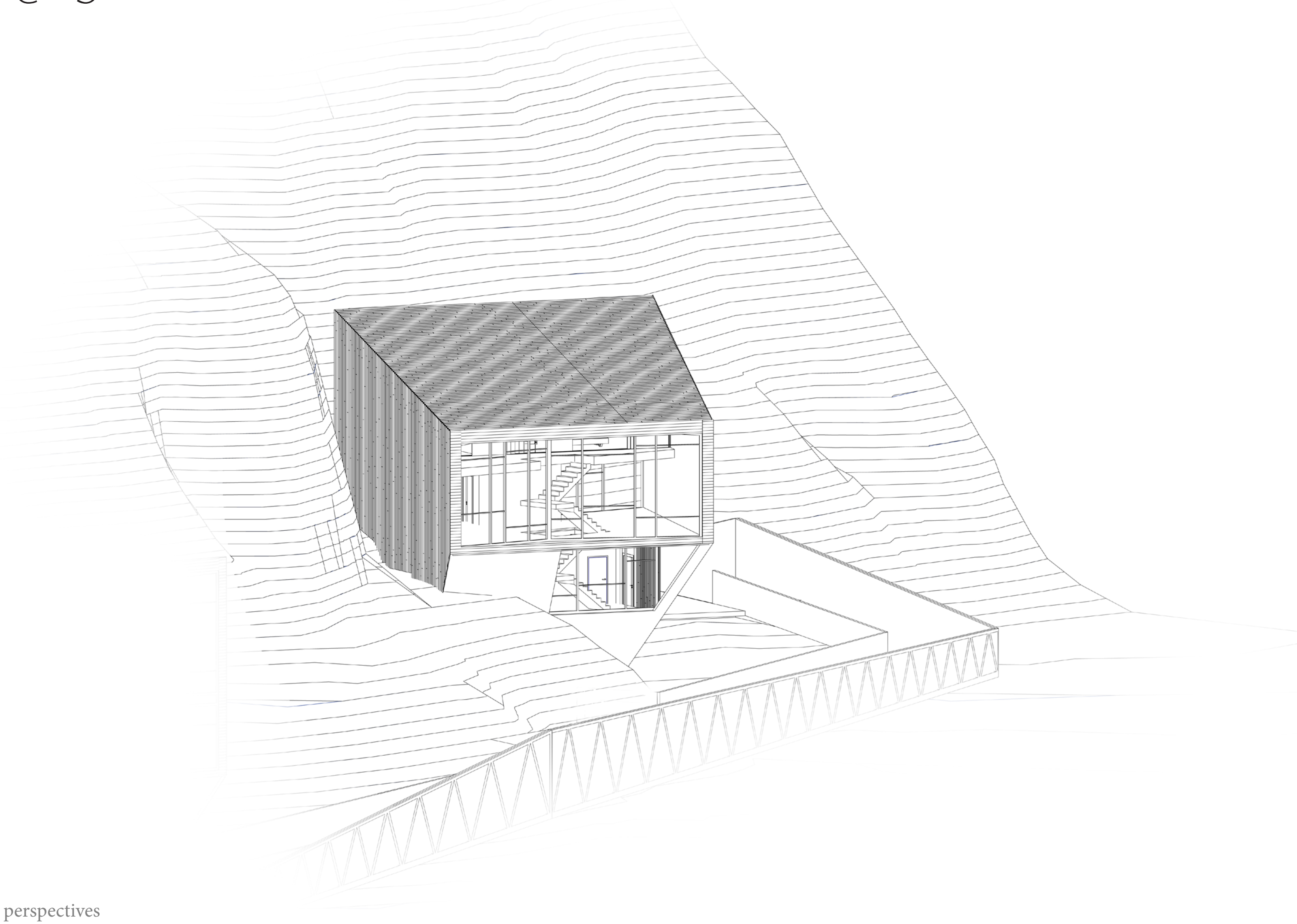
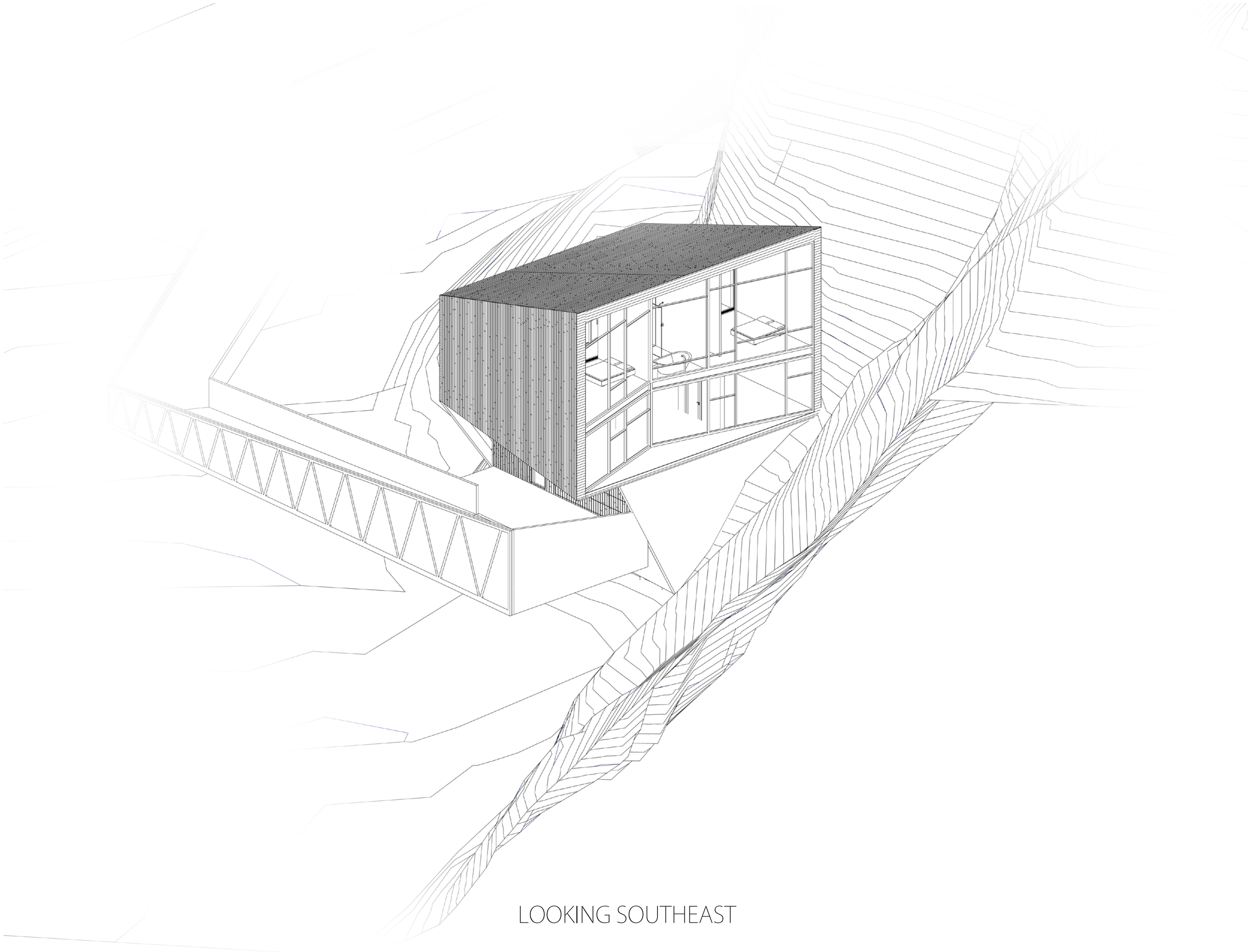


Figure 91: House 5 perspectives

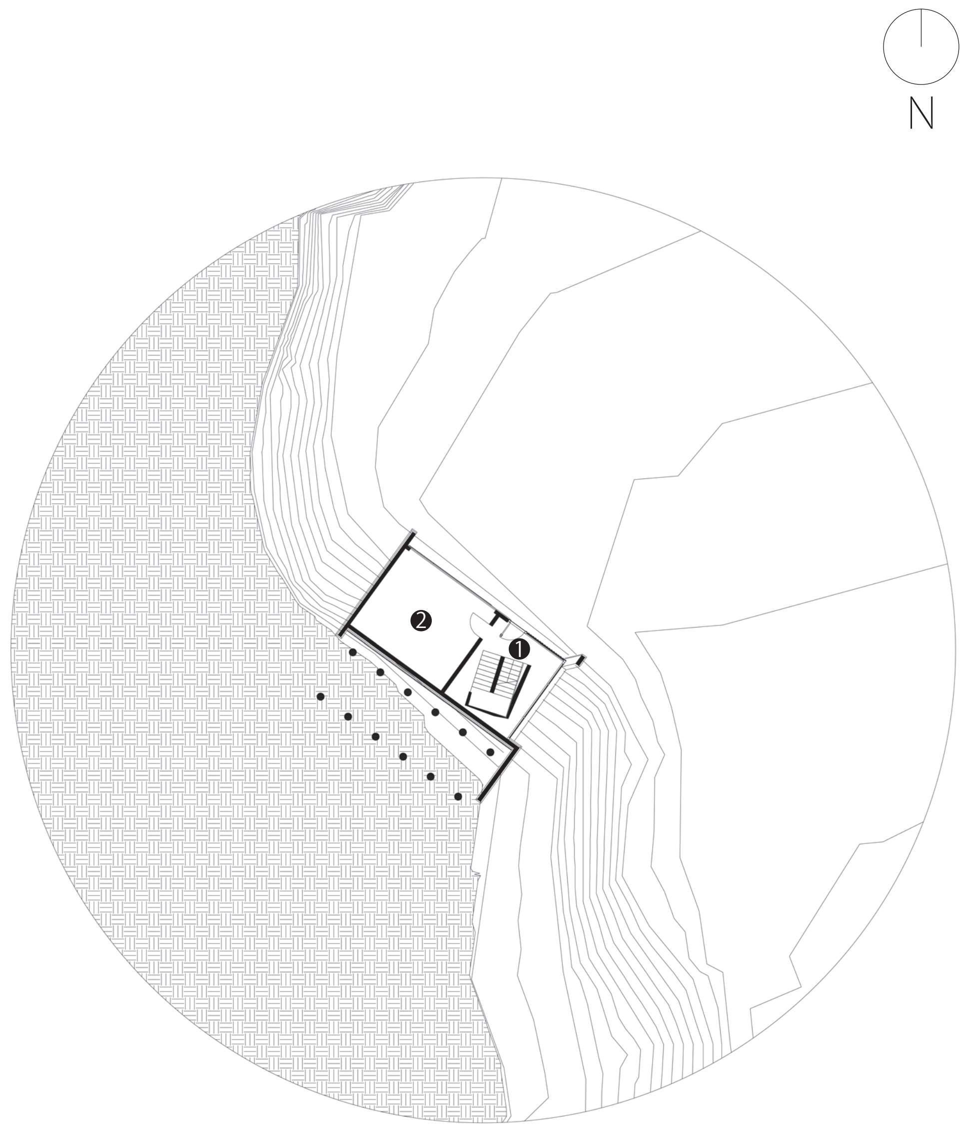
LOOKING NORTHWEST



LOOKING SOUTHEAST

House 5

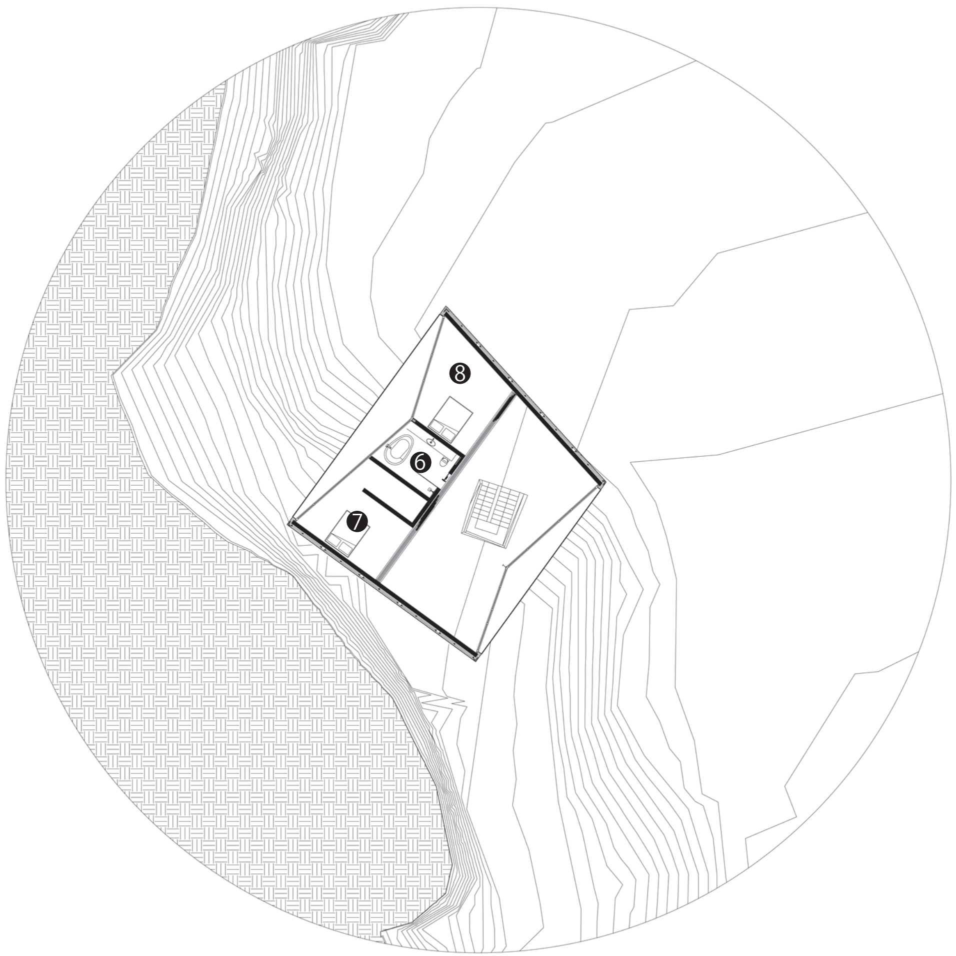
1. entry
2. garage
3. kitchen
4. dining
5. living
6. bathroom
7. master bedroom
8. bedroom
9. study



GROUND FLOOR

Figure 92: House 5 plans,
Scale: 1:400 at A4
1:200 at A2

FIRST FLOOR



SECOND FLOOR

4.4. An architectural discussion

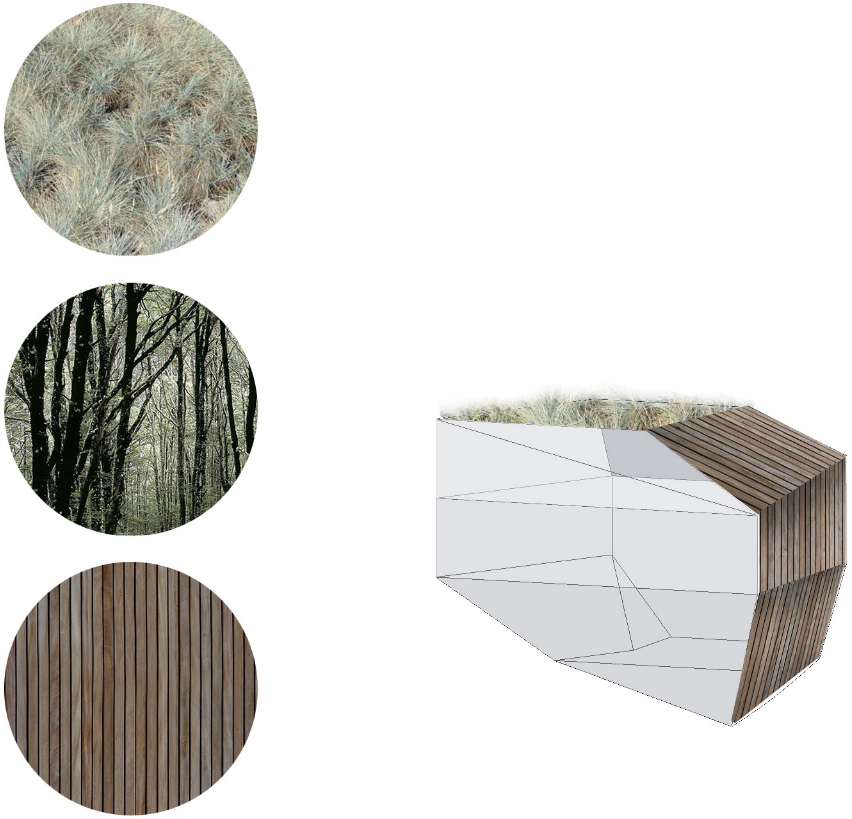


Figure 93 : Early concept showing relationship between form and materials (blue tussock grass, black NZ beech, Cedar - Author's own

How do the houses embody Norwegian ideologies, namely the resonation of design and nature?

It was essential to develop a design which engaged the occupants with the surrounding environment. Norwegian architecture creates this focus on the environment by using minimalist interiors and large windows. In this way, the interior architecture and design does not try to compete or detract from the outlook, and the view of nature becomes the focus, much like a large painting in a white walled room is the centre of attention. The large windows immerse the occupant in the surroundings.

The houses have transparency in one direction and solidity in the other. The wooden form wraps around the house which is open across the y axis but closed along the x.

The site offers a dramatic outlook across the rocky bay and is surrounded by plant life. On the first floor, transparency across the building is achieved with an open plan. To maintain transparency across the mezzanine floor the walls of the bedrooms slide across to create an unobstructed view right through the building.

The cladding integrates the houses into the environment while different species and lath widths and spacing differentiates one dwelling from another. The focus on articulating timber forms with simplicity.

Figure 94: Interior render of mezzanine floor featuring sliding timber partitions to open up or close off the private areas (House 5) Walls exposed CLT white washed, flooring is White Oak - Author's own

Figure 95: Cross laminated timber finish, architectural grade specified for interior surfaces which are to be exposed and white washed to appear like render above - Stora Enso

How have the designs reflected clarity, simplicity and honesty of materiality; intrinsic to Norwegian design?

The detailing reflects minimalist notions . The interior walls are the CLT structure with an architectural grade finish. The ceilings are similarly the CLT floor structure with an architectural grade finish; CNC routered channels for lighting cables allowing it to be hidden behind timber slats held into the ceiling with a magnetic clipping system. Internal walls contain the same detailing system to conceal cables and pipes. This system hides the large metal L plates which secure the walls in place and which are integral to the structural system.

To ensure a sufficient sound barrier between floors, a cavity was required to reduce the sound of impact [caused by people walking] (Xlam) This cavity hides cables and pipes and means the finished flooring system can be installed to meet the walls accurately without the need of skirting to conceal the junction. Usually the skirting has an additional function which is to protect the wall from damage caused by items such as vacuum cleaners hitting it. While skirting is a functional addition to plasterboard walls which are partial to damage from relatively low impact, solid timber is much more resilient.

As the openings for doors are CNC cut and thus a perfect cut, they require no architrave to hide inaccuracies and thus a clean look is achieved. Furthermore, this allows the layers of the CLT to be exposed, expressing the structure as an architectural detailing feature.

Figure 96: View looking northeast at House 1 and House 2 from road

Figure 97: Living area

Figure 98: Kitchen

Figure 99: Bathroom and second bedroom on mezzanine floor [house 1]. Features sliding timber partitions to completely open floor so the house is entirely transparent along that axis

Figure 100: Exterior view of house 5 from bridge, looking northeast

Figure 101: Section

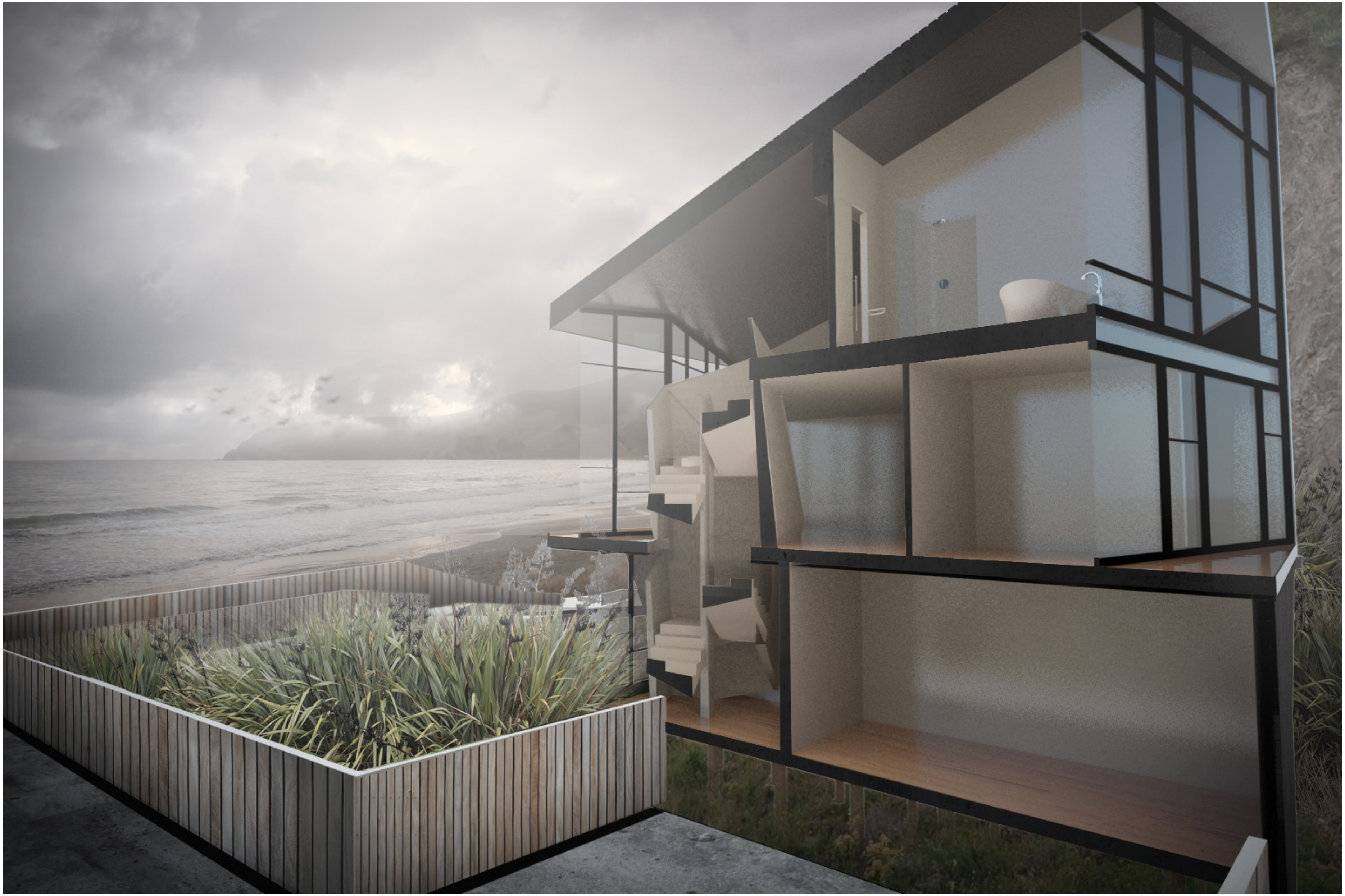


Figure 102: View of living area from staircase

5 Conclusion

5.1. Conclusion and future agenda

The primary intention of the thesis was to explore the possibilities of augmenting prefabrication with the context of a hill site. The aim was to demonstrate an approach for prefabrication of a residential architecture catered to the specific landscape of Wellington. Prefabrication to date has largely presented rectilinear buildings, a style which has become synonymous with manufactured housing. However, influential writers note that the construction method is not bound to such rigid orthogonal formal expression (Smith 251). Yet, in order for prefabrication to be widely utilised in the housing market, customisation and flexibility must be attainable (252). The hill side site requires considerable flexibility from the prefabrication system to meet the complications the topography imposes. This is essentially found in hybrid prefabrication, which combines the customisation of a panel system with the efficiency of modular components. The system allows the architectural form to express the context of the landscape by generating non-orthogonal/Euclidean designs, and challenging the rigid mould of rectilinear prefabricated structures. Opportunities for customisation and design flexibility enhance the capacity for contextualisation, so that instead of imposing a universal architecture, the design can respond to the specific conditions.w

This thesis presented a body of research investigating the theory and precedents of contemporary Norwegian architecture. This allowed the identification of a highly complementary means of engaging architecture with the natural landscape. It was found that by gently siting a building on the land; the landscape below was preserved and 'unscarred', meaning the building consciously responded to the topography as the architecture was adapted for preservation. The architectural form itself additionally required a response to the topography in order to avoid being perceived as divorced from the context; a universal entity. Norwegian architecture demonstrated the application of non-linear forms, whether sliced, jagged, folded, or undulating, which engaged the architectural form with the specific context presented by the site. The form appeared so precisely catered to the site that it was incomprehensible it could be replicated in a different context. It was particularly stimulating to see forms which were fitted to the terrain, following the landform and changing course to fit around features of the land. It was concluded that rectilinear forms do not relate well to the asymmetry and variation in the landscape of Wellington. The houses I presented in design study two and the developed design both express faceted forms. The final design study amplified the concept of fitting the form to the landscape with the cladding meeting the land and cut to fit that specific slope and land variances. The form responded to the specific climatic conditions being designed to minimise the effect of wind forces by 'folding' the windows inwards, a similar technique is implemented in Cabin Verdehaugen by Fantastic Norway.

To investigate the core topic, the limitations and technical restrictions inherent to hill sides were determined. Through this knowledge, the architectural designs responded to meet these challenges. By adopting the philosophy of the architecture solves the problem of the slope rather than altering the slope to fit to the architecture, these limitations formed a valuable framework for the design to work within, narrowing the broad possibilities. This lead to the reinterpretation of the pole house which tip-toes the building on the topography. From a technical perspective, this foundation method minimises the risk of landslides, particularly for acute angled sites as the stability of the slope can be compromised with the cut and fill method. Altering the natural course of water by embedding a building into the land requires extensive consideration for drainage systems, which, if inadequate or blocked can cause landslides. The forms of the houses are faceted with inset windows, a direct response to not only Wellington being a high wind region, but also the known amplification of wind forces which occurs on hill sides. Further design moves which presented a technical design response to the slope included running the walls parallel to contour lines, designing stairs to follow the grade wherever possible, specific access considerations and careful construction planning. The design moves in effect alleviated the multitude of technical challenges associated with hill sites.

To determine the scope of design typologies for hill sites, a matrix was formulated which, when analysed through design studies, determined the most appropriate typologies for specific contexts.

The research, through experimental design, demonstrated the possibility of adapting a prefabrication method to meet the demands of a sloped site. Due to the utilisation of hybrid prefabrication and CNC technology, the capacity for design flexibility and customisation was maximised, as evident in the designs. Hybrid prefabrication presented the combination of a panelised system with modular bathroom units, and was implemented as it delivers the benefits of less onsite construction time and a high quality of finish while maintaining design flexibility. Contextualisation is reflected in the form of each house, where the panels are customised to fit the unique variations in topography underling each of the five structures. As the CNC machine can cut any shape into CLT, the design opportunities were vast; yet for hill site construction, this flexibility is paramount if typologies specific to hill sites are to be implemented. Five axis routering additionally means panel joints were not restricted to 90 degree or 180 degree angles at junctions. Thus, the form of the buildings engages with the landscape, breaking away from the universal rectilinear forms prefabrication so often presents. By modifying the jointing method to incorporate structural steel angles at corners; concealed by rebates which utilise routering technology and timber veneer, the simple, clean aesthetic was achieved.

Although this is one example of the possibilities, it provides a foundation for further design concepts which may utilise prefabrication methods for hill site construction. The framework of technical limitations for hill sites, along with the typological matrix which has been established within this research, is significant data further explorations can look to build upon. Additional research may lead to the exploration of the downhill typology using this construction system, or present the application of an alternative method of prefabrication. By testing other prefabrication methods in detail with a design led research approach, this research could certainly be enriched further. Likewise, a full cost analysis and feasibility study of the design would be essential for supporting its application into practice.

Another strand of research, which was subordinately explored within this thesis but not fully optimised, was the method of digital modelling. By constructing the prefabrication system in Revit parametrically with all the jointing details, the system could be applied to any conceptual mass. As there was inbuilt quantity data for these parametric components I created, this could be linked to cost data, which would effectively produce immediate cost estimates for various conceptual designs using this prefab system. I certainly intend to optimise this research in the near future.

The outcome of this research demonstrates that prefabrication can provide great opportunities for alleviating the many technical challenges which hill sites present. When the prefabrication system is carefully implemented and adapted for customisation, it has the potential to form typologies specific to an inclined site. It is hoped, in doing so, that prefabricated houses will be contextualised to respond to the topography of Wellington and reflect our "spirit of place".

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Figure 95: Stora Enso, CLT – Cross Laminated Timber, 2013
Retrieved from: http://www.clt.info/en/produkt/

Figure 96: Author's own Revit digital model and application of materials, base rendering in 3ds Max by James Hirata, Author's own Photoshop overlays of materials, Render of house 1 and 2, 2013

Figure 97: Author's own Revit digital model and application of materials, base rendering in 3ds Max by James Hirata, Author's own Photoshop overlays of materials and background images, Render, 2013

Figure 98: Author's own Revit digital model and application of materials, base rendering in 3ds Max by James Hirata, Author's own Photoshop overlays of materials and background images, Render, 2013

Figure 99: Author's own Revit digital model and application of materials, base rendering in 3ds Max by James Hirata, Author's own Photoshop overlays of materials and background images, Render, 2013

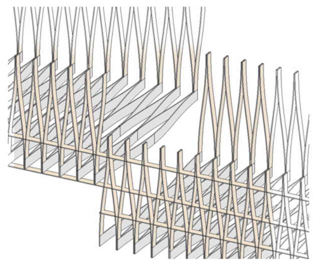
Figure 100: Author's own Revit digital model and application of materials, base rendering in 3ds Max by James Hirata, Author's own Photoshop overlays of materials and background images, Render, 2013

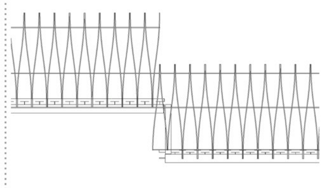
Figure 101: Author's own Revit digital model and application of materials, base rendering in 3ds Max by James Hirata, Author's own Photoshop overlays of materials and background images, Render, 2013

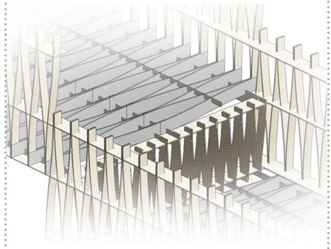
Figure 102: Author's own Revit digital model and application of materials, base rendering in 3ds Max by James Hirata, Author's own Photoshop overlays of materials and background images, Render, 2013

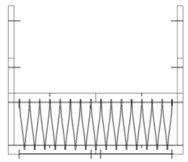
6 Appendix

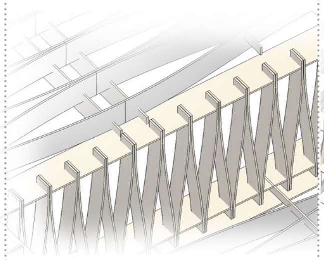
1.

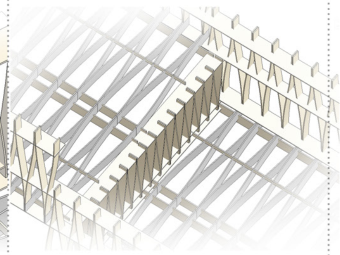












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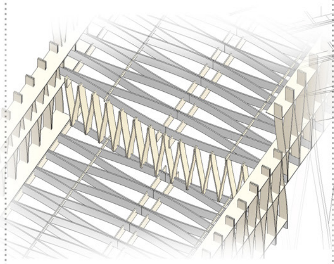
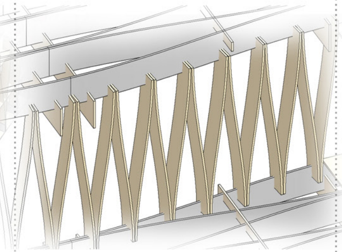
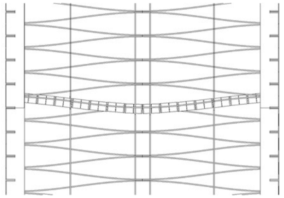
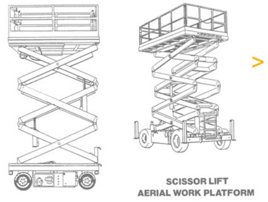




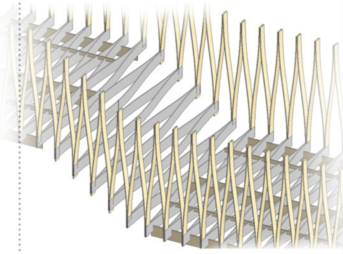
These diagrams express different strategies for applying the clip raft to an incline. The split level typology is explored with an 1800mm step. The first strategy attempts to tie the lattice perpendicular to the rest of the clip raft structure. A straight wall section is used which has the advantage of simplicity, but does not harmonise with the geometry in the way option two does. Option two follows the curve of the leaves, however this faces angle tolerance issues.

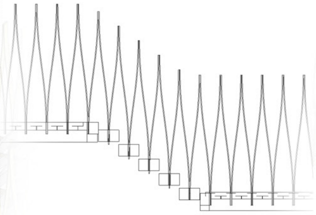


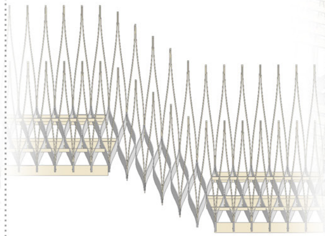


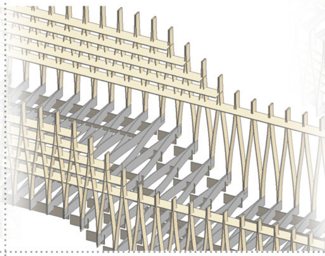
One advantage of using the clip raft system is the weight of the elements. For many hill sites, hiring a crane is not an option because of accessibility issues. A scissor lift may be the only practical aid, and these can lift up to approximately a tonne. Walls can often be simply tilted up; but it's the roof which can be an issue. This system could prove to be an effective roofing solution with the possibility of combining it with other systems.

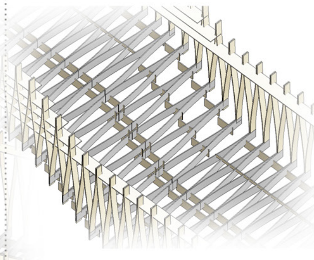
3.











NEXT STEP

Foundation!! Test this system with poles

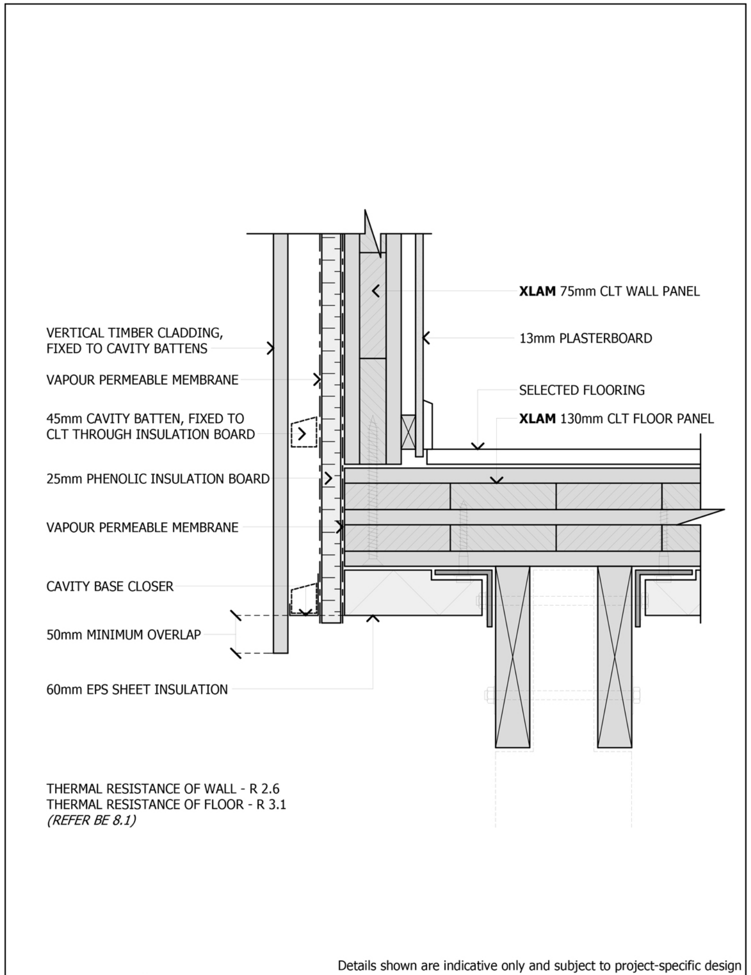
Double height space!!

Test Mark Southcombe's Jigsaw house with a split level typology.

Combine systems

Appendix 1: Author's own testing of clip raft

6.1. Technical Data



XLAM + POLE SUB-FLOOR

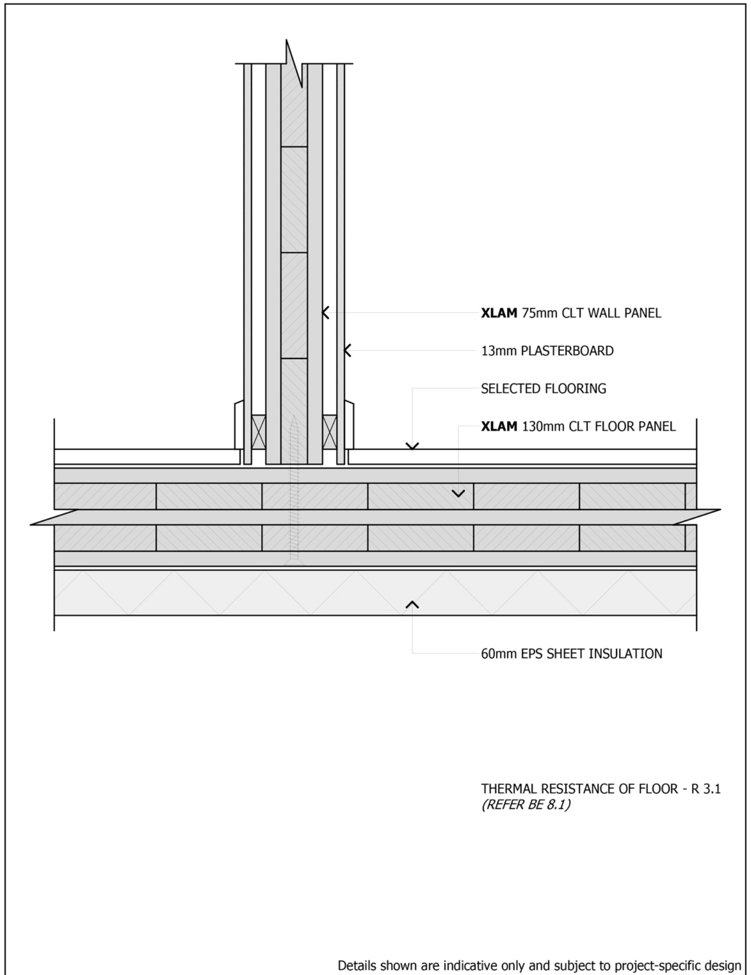
XLam NZ LTD

Telephone: +64 (0) 3 538 0930
Email: enquiries@xlam.co.nz
Web: www.xlam.co.nz
57 Beatty St, Tahunanui, Nelson 7041, New Zealand

V 1.1
Date. 08.05.13
Scale. 1:5 at A4

BE 1.5

Appendix 2 XLam



INTERIOR XLAM WALL TO FLOOR

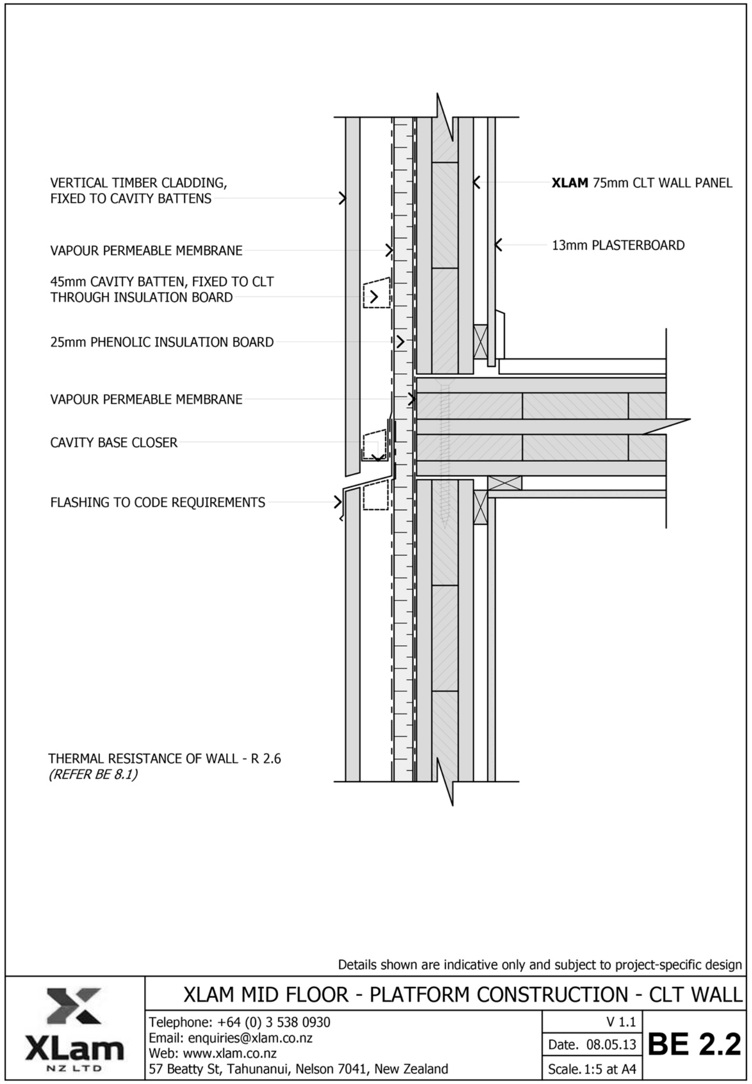
XLam NZ LTD

Telephone: +64 (0) 3 538 0930
Email: enquiries@xlam.co.nz
Web: www.xlam.co.nz
57 Beatty St, Tahunanui, Nelson 7041, New Zealand

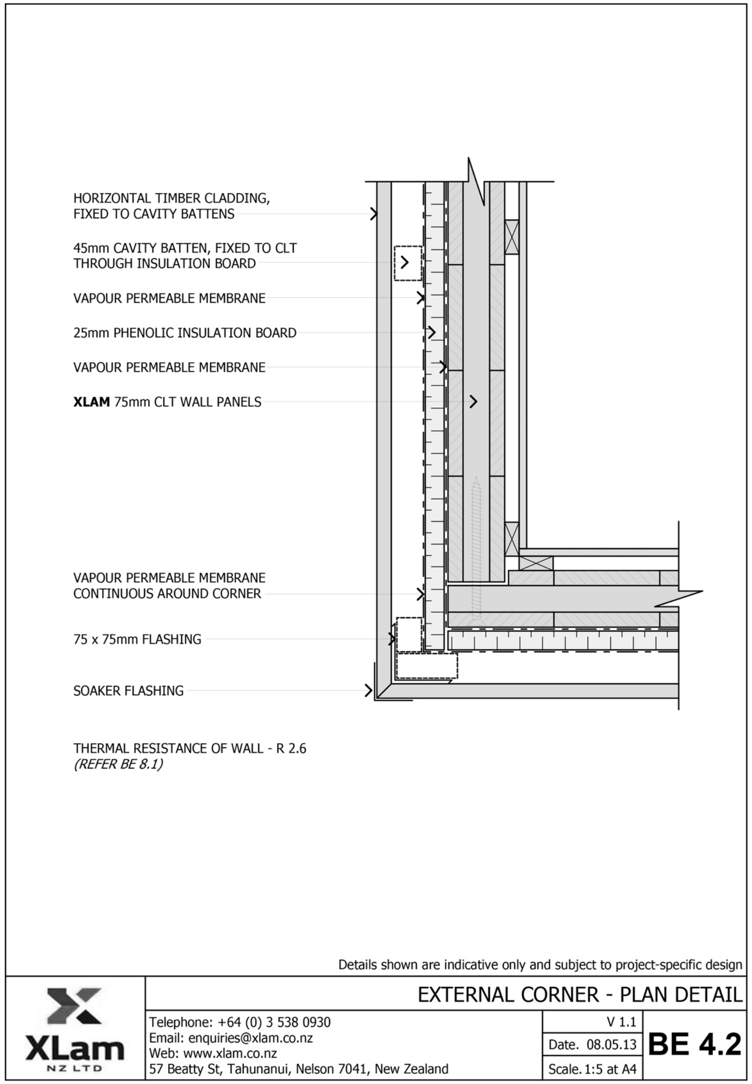
V 1.1
Date. 08.05.13
Scale. 1:5 at A4

BE 1.7

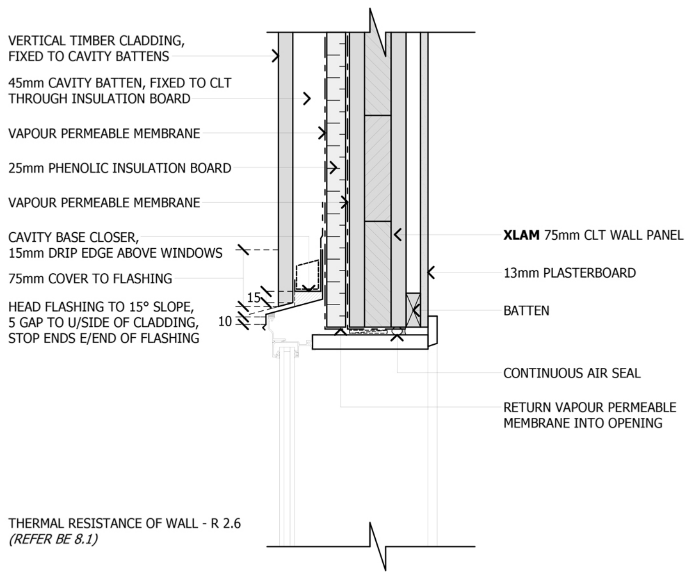
Appendix 3 XLam



Appendix 4 XLam



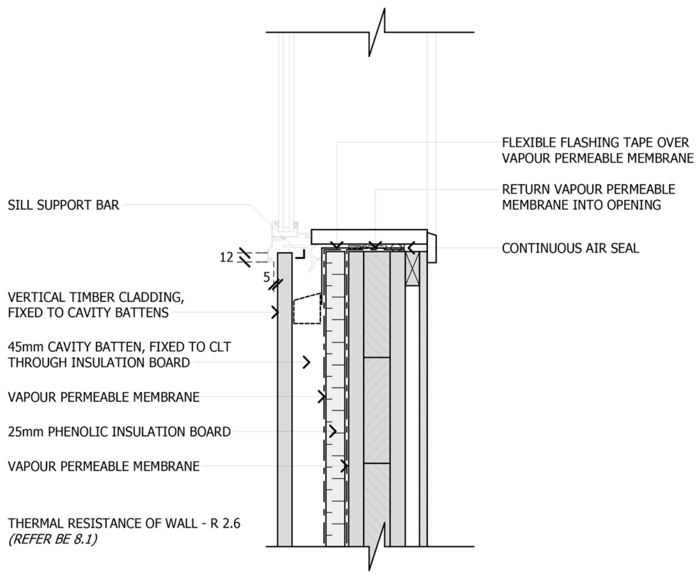
Appendix 5 XLam



Details shown are indicative only and subject to project-specific design

XLam NZ LTD	WINDOW HEAD		
	Telephone: +64 (0) 3 538 0930 Email: enquiries@xlam.co.nz Web: www.xlam.co.nz 57 Beatty St, Tahunanui, Nelson 7041, New Zealand	V 1.1 Date. 08.05.13 Scale. 1:5 at A4	**BE 5.1**

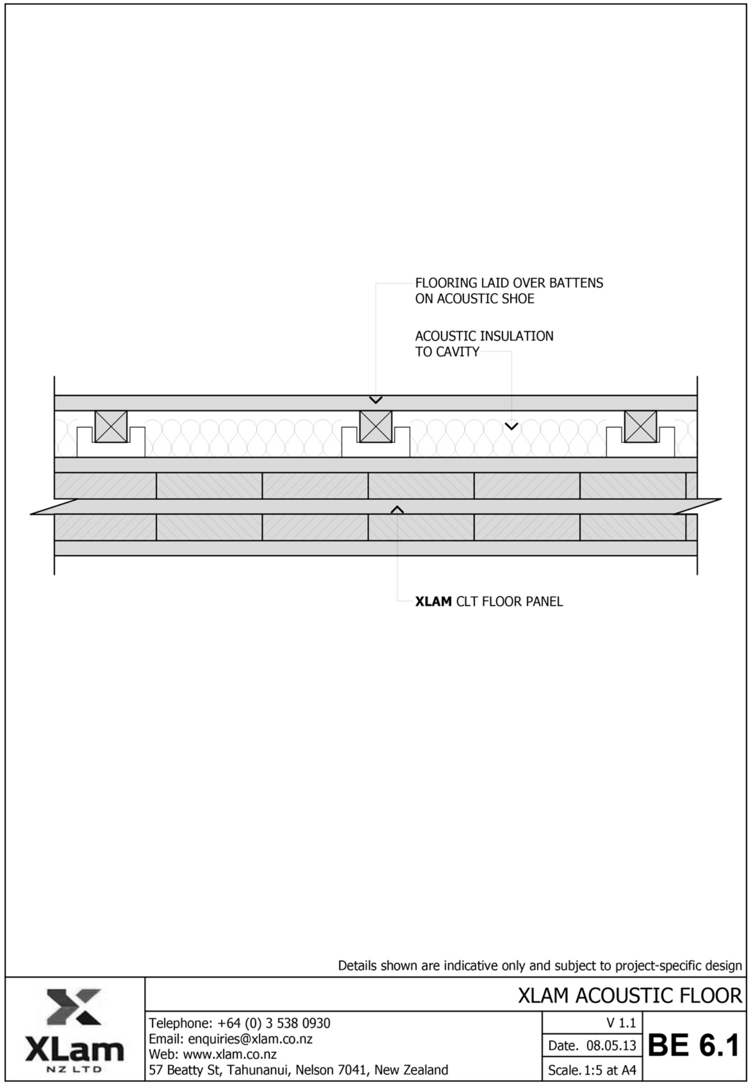
Appendix 6 XLam



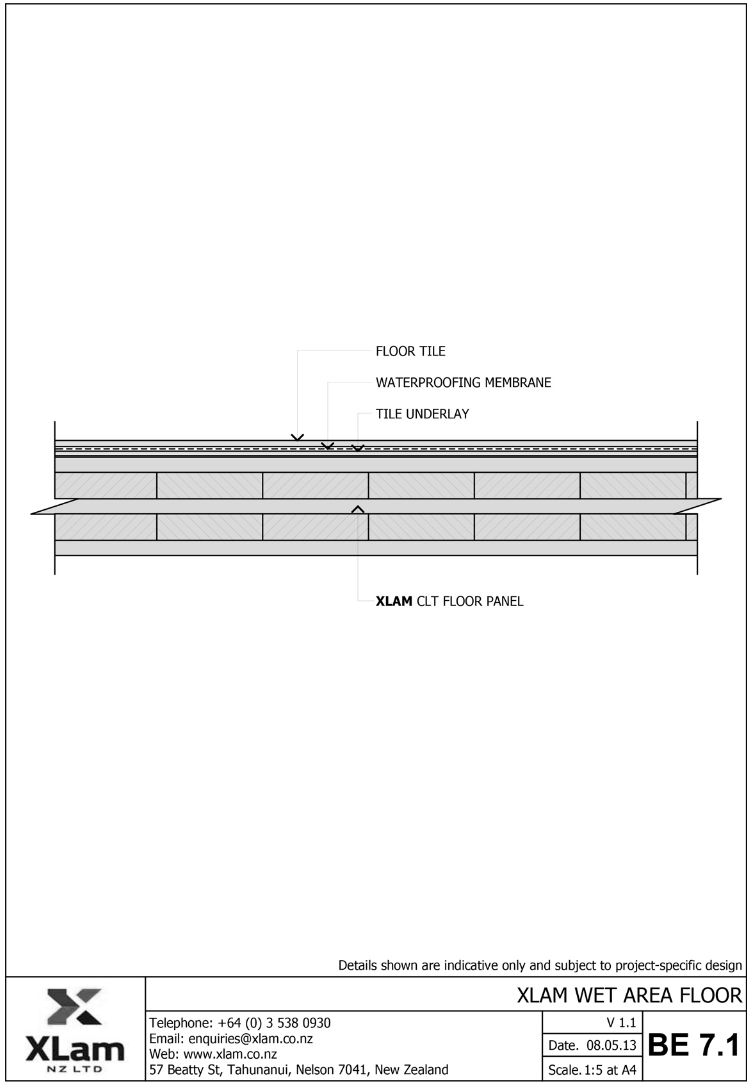
Details shown are indicative only and subject to project-specific design

XLam NZ LTD	WINDOW SILL		
	Telephone: +64 (0) 3 538 0930 Email: enquiries@xlam.co.nz Web: www.xlam.co.nz 57 Beatty St, Tahunanui, Nelson 7041, New Zealand	V 1.1 Date. 08.05.13 Scale. 1:5 at A4	**BE 5.3**

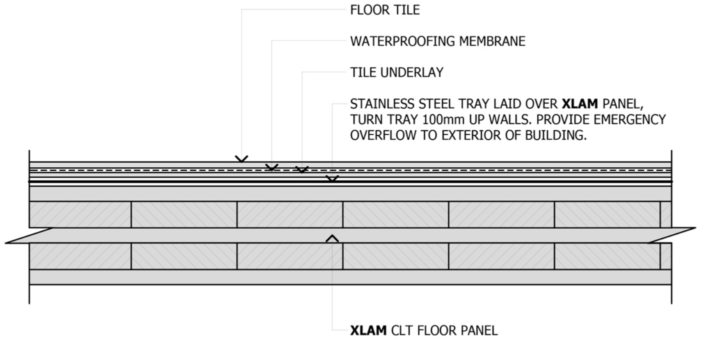
Appendix 7 XLam



Appendix 8 XLam



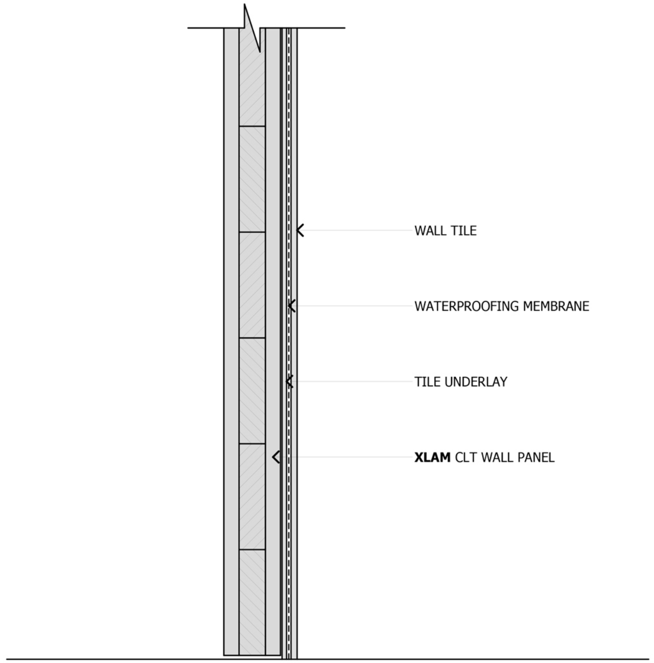
Appendix 9 XLam



Details shown are indicative only and subject to project-specific design

XLam NZ LTD	XLAM SHOWER FLOOR		
	Telephone: +64 (0) 3 538 0930 Email: enquiries@xlam.co.nz Web: www.xlam.co.nz 57 Beatty St, Tahunanui, Nelson 7041, New Zealand	V 1.1 Date. 08.05.13 Scale. 1:5 at A4	BE 7.2

Appendix 10 XLam



Details shown are indicative only and subject to project-specific design

XLam NZ LTD	XLAM WET AREA WALL		
	Telephone: +64 (0) 3 538 0930 Email: enquiries@xlam.co.nz Web: www.xlam.co.nz 57 Beatty St, Tahunanui, Nelson 7041, New Zealand	V 1.1 Date. 08.05.13 Scale. 1:5 at A4	BE 7.3

Appendix 11 XLam

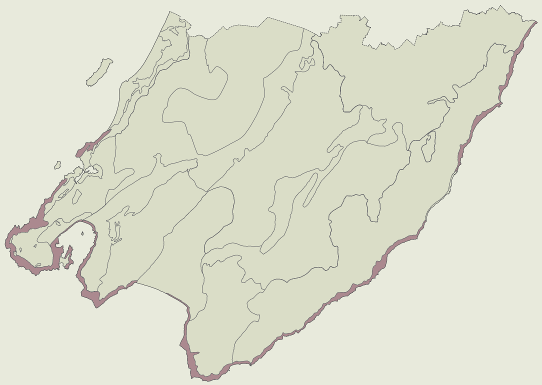
GUIDE TO CALCULATING THERMAL RESISTANCE FOR A CLT BUILDING ENVELOPE

BUILDING ELEMENT	R-Value	FLOOR	WALL	ROOF
Internal surface resistance	0.09	0.09	0.09	0.09
Interior lining 13mm plaster board	0.06		0.06	0.06
20mm still air gap	0.16		0.16	0.16
60mm CLT panel	0.5			
75mm CLT panel	0.625		0.625	
90mm CLT panel	0.75			0.75
105mm CLT panel	0.875			
130mm CLT panel	1.08	1.08		
145mm CLT panel	1.22			
175mm CLT panel	1.46			
60mm EPS sheet insulation	1.88	1.88		
25mm phenolic insulation board	1.4		1.4	
90mm fibreglass batt insulation	2.6			2.6
Ventilated cavity	0.07		0.07	0.07
19mm wood cladding	0.16		0.16	
Metal roofing	0			0
Exterior surface resistance	0.03	0.03	0.03	0.03
Total Construction R-Value		**3.08**	**2.595**	**3.76**

NOTE: IN PRACTICE THE TOTAL CONSTRUCTION R-VALUES WILL VARY FROM THE ABOVE TO TAKE ACCOUNT OF FACTORS SUCH AS THERMAL BRIDGING THROUGH PURLINS AND BATTENS, PENETRATIONS ETC.

09: Rocky coastal zone

Wairarapa coast (excluding Riversdale), Ngawi and Lake Ferry to north of Eastbourne. Makara, Pukerua Bay and coastal escarpment to Paekakariki. In Wellington – Thorndon, Mount Victoria, Hataitai, Berhampore, Miramar Peninsula Bays, Seatoun and Southern Wellington Bays (not Lyall Bay – see Duneland)



Environmental factors:

Strong, salt-laden winds can cause physical damage to plants. Shelter is important for good plant growth as strong winds also cause drying out. Generally frost-free.

Past landscape: Wind and salt-resistant shrubland, dominated by bluffs and steep escarpments. In gullies and more sheltered parts originally there was a mixed forest of trees adapted to the stresses of excessive drainage and salt.

Plants we recommend:

Trees

Big (b) = >15m Medium (m) 10-15m Small (s) = <10m
Akeake (s) (green, not purple form), akiraho (s), broadleaf (m) (*Griselinia littoralis* and *Griselinia lucida*), cabbage tree (m), kohekohe (b), karaka (b), ngaio (m), marble-leaf (s), taupata (s), tree hebe (s), whārangi (s) kōwhai (m). Note: a number of species of kōwhai are recommended for the Wellington region: *Sophora chathamica*, on the Miramar Peninsula, *Sophora molloyi* on the south coast and *Sophora microphylla* throughout the rest of the region.

Shrubs

Local Wairarapa endemics: *Brachyglottis pentacopa, Brachyglottis compacta*. Wellington endemics: *Hebe elliptica* var. *crassifolia, Melicytus obovatus*. Appropriate for both the Wairarapa and Wellington: *Coprosma crassifolia, Coprosma propinqua, Coprosma rhamnoides,* wild Irishman, niniao, coastal tree daisy, koromiko, sand coprosma, sand daphne, shrubby tororaro, thick-leaved māhoe. For Wairarapa add corokia to this list.

Climbers (c) and scramblers (s)

NZ ice-plant (s) small white clematis (c), leafless lawyer (s), pōhuehue (s), shore convolvulus (s), NZ spinach (s), *Fuchsia perscandens* (s/c), leafless clematis (s/c).

Ferns (f), Grasses (g), sedges (s) and rushes (r)

Necklace fern, sweet brake (f), shining spleenwort (f), hound's tongue (f), jointed wire rush (r), spring-flowering toetoe (g), silver tussock (g), *Ficinia nodosa* (s).

Other plants

Coastal flax, creeping pratia, renga lily, sand bidibid, speargrass, sea spurge, shore groundsel, *Linum monogynum*.

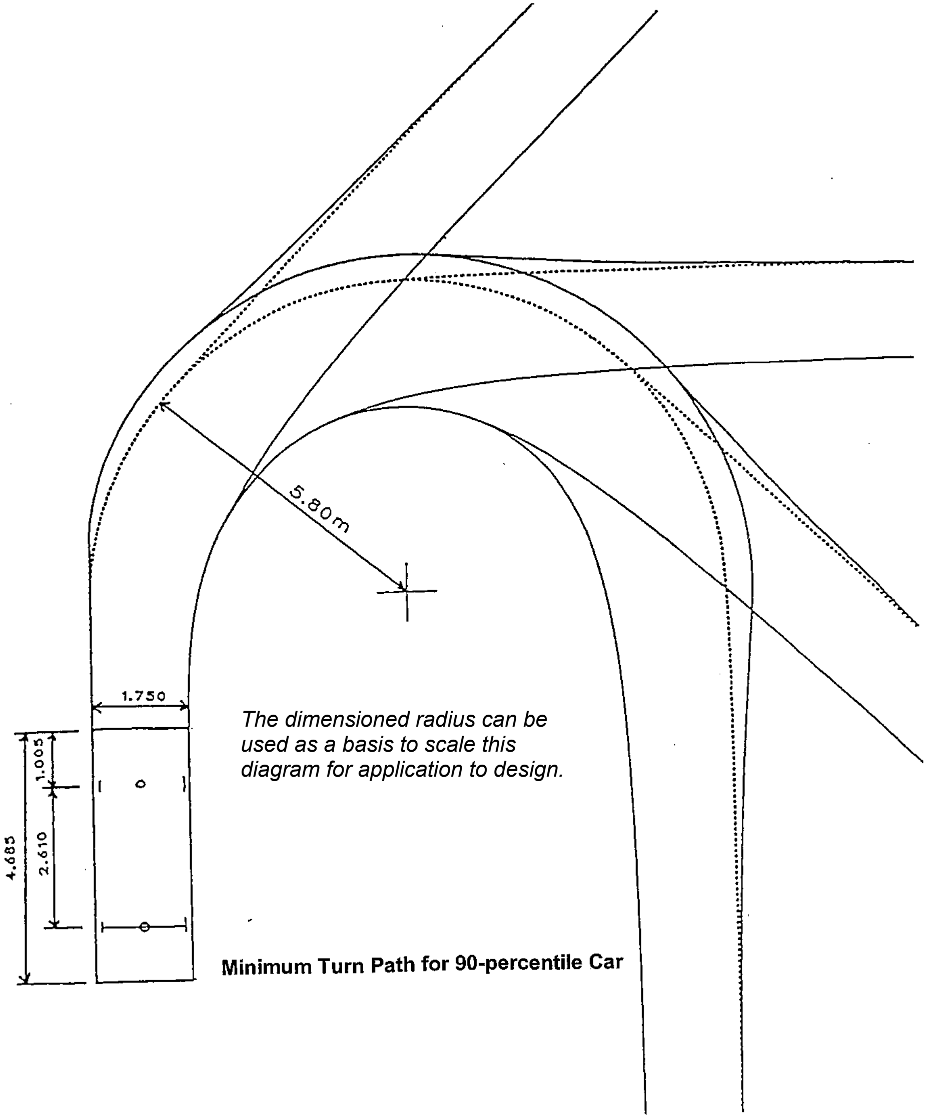
Look for these symbols in the main list (p46) for more plants to plant in this zone:

PUKA (BROADLEAF)
Griselinia lucida

Did you know?

Shrubby tororaro (*Muehlenbeckia astonii*) is a nationally endangered species. It is at its northern limit in the Wellington region. Only about 50 individual plants survive in the wild in the North Island. Plant it for a superb hedge

Appendix B5 – Minimum Turn Path for 90-percentile Car



The dimensioned radius can be used as a basis to scale this diagram for application to design.

Minimum Turn Path for 90-percentile Car