Modular Pre-fab Housing: A Scientific Approach

Graduate Thesis Report
by
Nick Marinos

School of Architecture • University of Miami

Spring 2011
MODULAR PRE-FAB HOUSING: A SCIENTIFIC APPROACH

The Challenge: to design a contemporary, modular, pre-fab building system for a tropical environment. Scout Key (FL) was chosen as the hypothetical site and is located about 34 miles north of Key West, along the US 1 (Overseas Highway). Measuring approximately 100 acres, it is an uninhabited island in the lower Florida Keys, with no amenities. Currently used as a Boy/Girl Scout campground, it is also the annual gathering spot for an amateur astronomers club.

The development is cost-effective in volume, self-contained and portable.

The Goal: to create a pre-fabricated structure (kit of parts) that will have multiple configurations and designed specifically for a tropical environment. I explored the organization/layout possibilities and rationalized a set of modular designs which allow for a flexible program arrangement.

The design was digitally prototyped — to achieve and validate the intended form, fit and function. Modern materials were used, with a strong emphasis on cost, weight and strength. Inspired by the geometric shape of a dodecahedron (*which is a Platonic solid*), I chose to use vertices to connect from, rather than walls. The concept also takes into consideration manufacturability issues and feasibility for mass production and distribution.
# Table of Contents

Abstract ................................................................................................................................. i
I. Introduction — Statement of Problem ............................................................................. 1
II. Research ......................................................................................................................... 6
   Primary Sources .............................................................................................................. 6
   Secondary Sources ....................................................................................................... 7
III. Case Studies .................................................................................................................. 9
   Case Study 1 — Maison Tropicale .................................................................................. 9
   Case Study 2 — Eames House ......................................................................................... 15
   Case Study 3 — Farnsworth House ............................................................................... 20
   Case Study 4 — Habitat ’67 ......................................................................................... 25
   Case Study 5 — Ramot 1 Housing Complex ................................................................... 28
IV. Hypothetical Project Site — Description & Analysis ..................................................... 31
   Scout Key — Location .................................................................................................... 32
   Scout Key — Climate Considerations ............................................................................ 33
V. Program .......................................................................................................................... 37
VI. Design ............................................................................................................................ 39
   The Approach ................................................................................................................... 39
   Design Features .............................................................................................................. 40
   Plans .................................................................................................................................. 42
   Elevations & Sections .................................................................................................... 43
   Modular Components - Kit of Parts ................................................................................ 44
   Modular Components - Features .................................................................................... 45
   Renderings ........................................................................................................................... 46
   Frame ................................................................................................................................. 47
   Interior ............................................................................................................................... 48
   3D Views ............................................................................................................................ 49
   Climate & Location Adaptability ...................................................................................... 50
   Bill of Materials ............................................................................................................... 51
VII. Conclusions .................................................................................................................. 55
VIII. Table of Figures .......................................................................................................... 56
IX. Bibliography ................................................................................................................ 58
Statement of Problem

The objective of this thesis is to design a contemporary pre-fabricated building system that can be used off the grid. This will be a portable structure that can be assembled and disassembled by hand and will be essentially a kit of parts. The building has been designed for a tropical environment, but it will also be possible to create alternative versions for other climate types, using a similar framing—but with alternative ventilation and heating systems.

Since this is a building system that is intended for off the grid use, efficiency is a paramount consideration. The system includes passive cooling methods. The weight has been kept as low as possible and the size, weight, and means of attachment of each individual component has been made so that only one or two people need to assemble the building, with simple hand tools.

The design was digitally prototyped—to achieve and validate the intended form, fit and function. Building Information Management (BIM) tools have been used to accomplish the design. The weight of the components have been enumerated. Design options were evaluated by simulation—from both thermal and structural points of view. The structure allows for appropriate wind resistance for a tropical environment. It will not be possible to include a foundation design, since the geotechnical soil details of a site are expected to vary significantly, but the weight of the building and the moments are known and, therefore, recommendations for the foundation anchors will be proposed.

This design is for a modular building system where multiple configurations will be possible. It is anticipated that the building system will be usable for both residential and commercial applications. In order to keep the design manageable, the design will be limited to a proposed usable area of less than 1000 square feet, as an open plan, two-story loft system with a simple circulation scheme. This way, the portable nature
of the design can be maintained and its use can therefore be maximized. It should also be easier to make successful business cases, to set up mass production and distribution schemes.

It is essential that lightweight materials be used, such as aluminum. Other possible modern materials have been evaluated and preference has been given for sustainable materials. The objective is to keep the costs low by having an efficient design, but cheaper materials that may contain toxic glues or other substances known to be hazardous have not be used. This project has been designed with regards to L.E.E.D. considerations. It is expected that any incremental costs will be offset by the benefits of use.

It is anticipated that such a building system can be used in tropical disaster-prone areas and should be a welcome alternative to the FEMA trailer concept. Unfortunately, tropical disasters such as the Katrina storm or the Haiti earthquake are inevitable, and it is hoped that this project can be seen as a welcome alternative or at least offer some ideas for a better solution to resolve an urgent situation. As seen from the case studies, such research has been typically funded by governments - usually with compromises. In this case, there are no political constraints and we are free to focus on the main objectives.

Although this is a portable and modular design, a hypothetical site was chosen to illustrate a proposed implementation as an example within a tropical setting. Scout Key is proposed as the project site (but it could just as well be any other tropical location). This Key was recently renamed in 2010. It was previously known as West Summerland Key. The site offers beautiful ocean views and is accessible by car or boat. There is a boat ramp at the southern end of the island.

This island is located along the US 1 (overseas highway) within the Lower Florida Keys, about 34 miles north of Key West – between mile marker #34 and #35. It is an uninhabited island measuring approximately 100 acres and has no amenities. It is used as a Boy/Girl Scout campground and is the annual gathering spot for an amateur astronomers club. This island has a relatively low elevation of roughly 30 feet above sea level, at the highest points. There are other islands in the area, but this site can be accessed by road transportation.

To maintain a reasonable level of comfort, air conditioning will be required, but can be significantly reduced by design. For this site, the building will need to be designed on stilts. This is necessary, so as to avoid flooding and also to promote
cross-ventilation and prevent dampness. Cross-ventilation can be facilitated by providing door and window openings on opposite sides of the building.

The weather profile charts for this site were derived from the EnergyPlus data sets developed by the US Department of Energy and can be found at:

http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm

Needless to say, this is a hot and humid site that will test the objective of designing a building in a tropical environment. The temperature never reaches 100°F, though, and the wind speed is typically around 14 mph – maximum – at ground level. The relative humidity usually ranges between 58% and 86%, and the solar radiation is quite high year-round. According to the data in the sun shading charts, it is apparent that shading is almost always needed.

A shading scheme is essential to minimize cooling power consumption and most of the glazing should be oriented to the north. This can be done by using exterior plants, such as bushes and trees.

Traditionally, homes in such hot and humid climates use high ceilings and have deep roof overhangs. The design includes a passive ventilation scheme, whereby the cooler air from the floor that originates from underneath the building is allowed to rise up to the high ceiling and exhaust through a roof vent as it heats up. Ceiling fans can help move the hot air upwards. Light-colored building materials should reduce heat absorption and cool roofing materials with high emissivity are used to minimize the heat gain. A simple, unobstructed circulation scheme with minimalist open interiors is thought to be best, since it will allow for unobstructed cross-ventilation.

Thermal performance have been evaluated by creating a thermal simulation model, given the choice of such materials. Material properties, such as thermal conductivity and thermal capacitance, are important for evaluating the design – based on both the insulation performance and the thermal storage capability of the materials.

Any potential insect and reptile problems can be avoided by having a raised building and screened porch areas.

To develop a thorough understanding of all the nuances and components involved in the design of modular, pre-fabricated housing, five very unique pre-
fabricated buildings were evaluated as case studies and are presented here in this Report.

Each case study focuses on design aspects that have been integrated in this thesis design project:

- **Maison Tropicale** – Jean Prouvé, Architect  
  *(Design Aspect: a tropical, modular construction)*

- **Eames House** – Charles & Ray Eames, Architects  
  *(Design Aspect: integration with landscape)*

- **Farnsworth House** – Mies van der Rohe, Architect  
  *(Design Aspect: an excellent example of a minimalist design)*

- **Habitat '67 Apartment Complex** – Moshe Safdie, Architect  
  *(Design Aspect: proposes a set of rules for urban living)*

- **Ramot 1 Housing Complex** – Zvi Hecker, Architect  
  *(Design Aspect: multi-family, organic design)*

The intensive research was both interesting and extremely valuable to the development of an initial design concept for the Scout Key site. The case studies will be discussed in further detail, complete with illustrations, in Section 3 of this Report.
The primary and secondary sources used in the compilation of this Report provided me with a wealth of information on the subject of modular, pre-fabricated building system design, sustainability, and climate issues inherent in a tropical environment.

**Primary Sources**

The idea for choosing the Jean Prouvé MaisonTropicale case study was initially inspired from the following book. There are many other examples, as well, since this is a book about pre-fabricated structures that have been built internationally. Some of the examples are not treated with the same depth of detail as others. In addition, information is given about the case studies regarding the Habitat '67 complex by Moshe Safdie and the Ramot housing complex by Zvi Hecker.


The following website gives an outline of a computational fluid dynamics approach to evaluate the thermal performance of the Farnsworth house. The Farnsworth house is an excellent example to evaluate because it is simple in structure and form and because these were some public complaints against the architect by the first owner (*Dr. Edith Farnsworth*), with regards to the lack of comfort.

The following book illustrates detailed floor plans, elevations, and site drawings of well-known low-rise and multi-story housing complexes. The Habitat '67 and the Ramot Housing complex plans and elevations are presented in detail. It also includes a brief synopsis for each design.


A brief history of the Eames house. This is the official web site of the Eames Foundation. The "bridge house" – as well as the current Eames house - site plans are found here.


A brief history of the Farnsworth house. This is the official web site for the house and is supported by the National Trust for Historic Preservation. The design intent of the house is contrasted with the landscape.


The *Poetics of the Technical Object* gives a very detailed account of Jean Prouvé’s life and his diverse scope of projects, which include buildings, furniture, cars, etc.. It is formatted as a collection of essays by various authors and is a very interesting book. This book gives ideas for fasteners and methods of assembly. There is a lot of information presented, both as illustrations and text.


Within the *Beyond Habitat* book, Moshe Safdie proposes a set of “urban” rules for a modular building system. Ideas about potential issues to be aware of while seeking to mass produce are discussed, given the author’s significant experience with the Habitat projects. The differences between Canadian and American business practice were contrasted and were especially interesting, as were the tumultuous political issues in Québec and Canada at that time.


This is a very detailed book (a standard) that describes natural forms mathematically. It is an excellent, extremely detailed book, but quite challenging.

*Modular Pre-fab Housing: a Scientific Approach*
to read since the physics and mathematical terminology is somewhat old fashioned (written in the 40’s). I read the first few chapters and it provides ideas for forms from a bird’s eye view perspective.

Plans, sections and elevations are included for both the Eames and Farnsworth houses. A brief history of these houses is also provided. The sections are short, but concise.

**Secondary Sources**

The *Whole Building Handbook* is an information research source that discusses materials which can be used to create healthy buildings, design methods with respect to conservation, the various ecological cycles that relate to the building process and its impact on the ecosystem, amongst other topics as well.

This book contains various discussions in essay form, with lots of illustrations and is about introducing eco-friendly solutions to help with the energy crisis of the 70’s. It is not a detailed book about this topic, but it touches on many areas (such as solar, wind insulation, etc.).

An illustration of how sustainable methods are used in a case study format (such as the use of timber and controlling household waste):

Interesting essays include “Assessing a Carbon Neutral Building Approach” and “Evolution of the American Zero Energy House.”
This book is divided into chapters that include: hot, cold, high (elevation) and wet. It is essentially a collection of essays and some are more useful than others. The introductions in each chapter were helpful.

Various pre-fabricated buildings were evaluated as case studies and are presented here. Each case study focuses on a specific issue that I consider critical to my proposed design.

**Maison Tropicale**

*Architect — Jean Prouvé*

Jean Prouvé first began looking at light building designs in the 1930's. He referred to them as "the tent and the hut." The "tent" — being a manufactured portable product that can be easily assembled and disassembled, and the "hut" — that is a building optimized for mobility and higher volume production, but without the portable feature (*i.e. the building is a permanent structure*). Jean
Prouvé was also known for his innovative furniture designs and his love of cars – particularly the Citroën, for which he designed many parts. Prouvé was commissioned in the mid-to-late 1930's, by various French government agencies, to research and create mass produced housing, small shed structures, and nomadic lodgings intended for the Corp of Engineers and other departments. He collaborated with Pierre Jeanneret (cousin of Le Corbusier) in the early 1940’s. He was also commissioned to design homes to re-house homeless war victims. It is interesting to see the evolution of his prototypes, as there is a consistency that is maintained throughout, and an engineered quality that is clearly evident from his drawings.

Jean Prouvé worked out of his office "Atéliers Jean Prouvé" in Nancy, France, to design the Maison Tropicale in 1949. The design was commissioned by the French Government. The objective was to develop postwar prototypes of portable pre-fabricated buildings that were intended for French colonial offices – for both residential and commercial applications. The building kit of parts were created in Jean Prouvé’s factory, located in Maxéville, France.

Only three Maison Tropicale buildings were assembled: one unit was assembled in Niamey, Niger (1949) – to serve as a schoolmaster’s house, and two units were assembled in Brazzaville, Republic of Congo (1951) – where one was used for a French Aluminum Information Office, and the adjacent other was used as the home of the Office Director. The Niamey building was assembled on a concrete slab and the other two buildings in Brazzaville were assembled on piles, due to the topography. The small Brazzaville model includes an area of approximately 720 square meters.
square feet, and the large model has approximately 950 square feet of usable area, not including the peripheral walkways – in both cases.

Fig. 4 - Maison Tropicale – Brazzaville Version – Plan

Fig. 5 - Maison Tropicale – Brazzaville Version – Section
The Maison Tropicale is a design which rests on girders that have the facility to be attached to above-ground, raised piles. It is a one-story, modular structure that is designed on a one-meter grid. The design features interior porticos, insulated panels, operable sunshades and a natural interior ventilation system. The system consists of the house's skeleton, which includes the "backbone" that is formed by the ridge beam, the "vertebrae" or ventilation system, and the "legs" of the very distinctive porticos. After site work is done and the skeleton is assembled, the panels are inserted to complete the walls, doors, and windows. The building uses nuts and bolt connections, and each part is designed so that it can be assembled or disassembled by only two people.

It is a watertight system, where most pieces are made up of aluminum – with the exception of the steel girders, the interior portico legs, and the panel glass porthole inserts.

The building is easy to transport, as everything (building frame, walls, doors, and windows) was designed to fit into two containers suitable for air transportation. Each container measured roughly 7.5' wide x ~39.5' long.
The three buildings were air lifted to Africa, where they were assembled and forgotten. Starting in 1996, after some publicity appeared in a magazine about the modernist structures of the former Brazzaville colony, there was a renewed interest in these buildings. In the years following (2002+), all three buildings were eventually dismantled, brought back to France, restored, and re-sold. Only the eerie remains of the columns stand today in the former Brazzaville site.
Fig. 10 - Remaining Columns – Brazzaville Site

Fig. 11 - Exhibition at Tate Modern (London) - 2008
Eames House
Architects — Charles & Ray Eames

Fig. 12 - Eames House — Site

The Eames house is located in Pacific Palisades, California and includes two structures: a home and an architect's studio. The back of the lot faces a retaining wall over which there is a beach front. The front of the lot faces a meadow. The buildings are located on a 3-acre lot.

Fig. 13 - Eames House — Bridge Plan vs. Current Plan
The initial plan, that is referred to as the "bridge design," was designed by Charles Eames and Eero Saarinen in 1945. These architects were commissioned to design efficient and inexpensive homes for the US Government, along with a group of other architects, to help with the postwar housing shortage during a residential housing boom after WW2. The design was completed and the steel parts were not available until 1948, due to the steel shortage after the war. During this waiting period, the husband and wife team of architects (Charles and Ray Eames) re-designed the project (in 1949) because Ray wanted to preserve the meadow. In the original "bridge design" plans, it can be observed that the buildings appear to cut across the meadow topography, and in the re-design version, the buildings are in line with the hills and appear to be much less invasive to the landscape.

The re-design apparently used the same amount of building materials as the "bridge design" – with the exception of an additional girder beam, which was needed for the new design. The building is built around a pre-fabricated steel frame that rests on a 10-foot structural grid, with colored panel inserts and an array of windows. The studio and home include ~1710 square feet and ~2605 square feet respectively, perhaps reflecting a preference for the home life.

![Fig. 14 - Eames House – Plans & Elevations](image-url)
Fig. 15 - Eames House – Structural Grid

Fig. 16 - Eames House – Structural

Fig. 17 - Eames House – Living & Working Spaces
This two-story design includes two separate buildings that are mutually aligned, with a space in the middle. There are clear partitions between living, working, and outdoor spaces.

The weather profile charts for this site were also derived from the EnergyPlus data sets (for nearby Santa Monica) that were developed by the US Department of Energy, and can be found at:

http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm

The comfortable temperature range for this site lies in the upper part of the temperature bands and therefore this site will need more heating than air conditioning. Sunlight is almost always desirable in the winter/spring months and is usually required in the summer/fall months, as well.
To summarize, this is one of the more comfortable climates, and shade can be used to prevent overheating. The buildings can be open to breezes in the summer and passive solar gain can be used to reduce heating costs in the winter months.
Farnsworth House

Architect — Mies van der Rohe

The Farnsworth house was built in 1951 for Dr. Edith Farnsworth (a nephrologist) in Plano, Illinois. This design was intended as a country retreat home.

The house was designed by Mies van der Rohe. It is regarded as a particularly important piece of architecture because it exemplifies the architect’s modernistic International Style. There are no remnants of traditional living in the house (i.e. no pictures, doors, walls).
This design is expressed with columns and beams. The house is made out of glass and steel, uses minimal amounts of materials, and appears to hover over a flat meadow. The structure is raised 5’ 3” above ground, since the site was prone to flooding.

The building rests in a pastoral rural setting and is located approximately 50 miles from Chicago. The house is a single, geometric, elongated rectangular form that lies parallel to the Fox River and the cross-axes from the main stairway entrance directly faces the river.

Structurally, it is a relatively simple design to understand and analyze. The house floor and roof are supported by I-beam columns that are spaced, using a 30’ x 40’ grid. The floor-to-ceiling height is ~16 feet. The single story house is enclosed with glass walls.

![Fig. 22 - Farnsworth House — Exploded Structural Components](image-url)
The plan is very straightforward. A den and a bedroom at opposite ends are linked longitudinally via a galley kitchen that is opposite a living room space. The space in the center of the house, beside the kitchen, includes two bathrooms, the storage area, and the central heating mechanical space. The building is heated by radiant coils, set in the concrete floor.
Natural cross-ventilation, and the shade of nearby trees, provide minimal cooling. The owner had voiced public complaints against the architect and claimed that the house was never comfortable.

The weather profile charts for this site were also derived from the EnergyPlus data sets that were developed by the US Department of Energy (for nearby Aurora) and can be found at:

http://apps1.eere.energy.gov/buildings/energyplus/cfm/weather_data.cfm

The temperature range for this site varies significantly between -10° F to 95° F. The sun shading charts indicate that sun is strongly desired in the winter/spring months and shade is usually needed in the summer/fall months. To get good passive solar heating, most of the glass area needs to face south (so as to maximize the winter sun), and design overhangs are required (to fully shade in the summer months).
Thermal mass can be used, such as tiles or slate or a stone-faced fireplace, to help store winter daytime solar gain and to achieve an appropriate thermal delay for summer comfort.

Fig. 27 - Farnsworth House – Climate Data
The apartment complex was designed by Moshe Safdie and built for the 1967 World’s Fair in Montréal (Expo ’67) – as a thematic prototype. The work began in 1965 and was completed in 1967. It was paid for by the Canadian Government. Safdie is considered to be amongst a group of utopian architects.

The complex consists of a four-block-long row of 158 pre-fabricated, rectangular, stacked concrete block houses. Each apartment was built from between one to eight modules, chosen from 354 unique designs. The concrete modules had integrated mechanical spaces but did not include the roof as a self contained unit – a mistake, according to Safdie.

The original design originated from Moshe Safdie’s thesis at McGill University in Montréal (1960). He was commissioned by the government to create a modernistic pre-fabricated structure. Safdie attempted to revolutionize the way homes were
built. He attempted mass production and though that it was more efficient to make a pre-fabricated building.

Each module was pre-fabricated and assembled by crane. It was originally much larger (~1000 units) and was designed as a modern version of a European hill town. The original design included shops and a school. Due to cost constraints, the design
was reduced to 158 apartment units that range from a 600 square foot (1 bedroom) unit to a 1700 square foot (4 bedroom) house. Each apartment has an open garden space (37’ x 17’’) that is formed by a lower apartment’s roof. Some modules are stacked as much as six stories high.

The project was initially considered a success, as it drew many to visit the site. However, this modular concept was not replicated, since it did not offer the promise of a lower production cost. The cost per unit was the same cost as building an ordinary townhome (for a build quantity between six-eight townhomes). There were
many other "Habitat" design spinoffs around the world, but none were built, except for the Habitat '67 complex in Montréal.

Most interestingly, in his book "Beyond Habitat", Safdie proposed a set of "requirements" which were essentially a set of criteria for space requirements and attributes necessary for one to lead a normal life, within a multi-unit apartment complex.

**Ramot 1 Housing Complex**

**Architect — Zvi Hecker**

![Fig. 34 - Ramot 1 Housing Complex - Exterior View](image)

The apartment complex was designed in 1972-74 and built in 1977. Commissioned by the Israeli Ministry, this highly unorthodox complex was built specifically for very orthodox Jewish families in Jerusalem.
The complex consists of 720 units for the stage 1 construction and an additional 280 units for the stage 2 construction. All were pre-fabricated dodecahedron (12 sides) structures and were assembled as stacked modules in a beehive-like configuration. A leaf and a hand were used as metaphors for the site plan. It is a very amazing design to see. Each unit appears to interlock with one another, but some of the top units look like rectangular masses within a polyhedral outer skin.

Within a unit, the large living room serves as a central distribution space, with hallway segment paths included – to provide paths to either 3 or 4 bedrooms. The
kitchen and washrooms are created from the wedges that result from the star shape. The 3 bedroom apartment units have areas that range from 678 - 1140 square feet. The 4 bedroom units have areas between 1259-1400 square feet and the 5 bedroom units have areas between 1377-1453 square feet.

The terraces make up for most of the irregular spaces within the complex and are considered the key to the plan, since they are both extensions to the living spaces and provide access to the building.

Figs. 39-41 (clockwise, from top) - Plans, Sections & Elevations; Site Illustration
Hypothetical Project Site: Description & Analysis

As mentioned earlier, the objective of this thesis is to design a contemporary, pre-fabricated building system that can be used off the grid. It has a portable structure that can be assembled and disassembled by hand and is essentially a kit of parts. The building has been designed for a tropical environment, but it will also be possible to create alternative versions for other climate types – using a similar framing – but with alternative ventilation and heating systems. Scout Key is the proposed hypothetical project site.

**Scout Key – Location**

MM 34-35, FL

*(previously West Summerland Key)*
Figs. 43-46 (from bottom to top) - Scout Key Site/Location
Scout Key – Climate Considerations

Fig. 47 - Scout Key - Climate Data
In this tropical climate, there are several considerations to address when designing a pre-fabricated building system that will be functional, efficient, sustainable, and – above all – comfortable:

- In this climate, air conditioning will always be required, but can be greatly reduced if building design minimizes overheating.
- Homes traditionally used lightweight construction with openable walls and shaded outdoor porches, raised above ground.
- Orient most of the glass to the north, provide shade & locate door and window openings on opposite sides of building – to facilitate cross-ventilation.
- Traditional homes in warm, humid climates used high ceilings and high operable (French) windows, protected by deep overhangs and screened porches – to prevent insect problems.
- Use light-colored building materials and cool roofs (with high emissivity) – to minimize conducted heat gain.
- Use open plan interiors to promote natural cross-ventilation and raise building well above ground – to minimize dampness.
- Underground vent pipes can use the cooler ground mass – to condition the incoming air.

- Window overhangs or operable sunshades (*extend in summer, retract in winter*) can reduce or eliminate air conditioning.

*Fig. 48 - Window Overhangs*
- use of ceiling fans or indoor air motion can make it seem cooler by at least 5°F

Fig. 49 - Indoor Air Motion

- include natural ventilation with windows oriented to prevailing breezes

Fig. 50 - Natural Ventilation

- minimize or eliminate west-facing glazing – to reduce summer and fall afternoon heat gain

Fig. 51 - West-facing Glazing Minimized
- use plant materials (*ivy, bushes, trees*) – especially on the west – to shade the structure

![Fig. 52 - Use of Plants for Shade](image)

- design the building to minimize overheating and the use of AC

![Fig. 53 - Efficient Design](image)
Since this will be a modular building system where multiple configurations will be possible, it is proposed that the program be limited initially to a usable area of less than 1000 square feet, as an open plan, two-story loft system with a simple circulation scheme. This way, the portable nature of the design can be maintained and its use can therefore be maximized.

This particular compact design configuration includes 1 loft bedroom, 1 bath, a living room, and kitchen – as well as a mechanical room centered above the lowest vertex of the space frame structure. It also has a large, retractable balcony and a stowable main entry staircase and – serving as a storm shutter system. This design uses a space frame as the primary structural element and the square footages are largely driven by the structural capacity of the space frame.

<table>
<thead>
<tr>
<th>HOUSING UNIT - SQUARE FOOTAGE</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Living Room</td>
<td>260</td>
</tr>
<tr>
<td>Kitchen</td>
<td>39</td>
</tr>
<tr>
<td>Loft Bedroom</td>
<td>253</td>
</tr>
<tr>
<td>Bathroom</td>
<td>47</td>
</tr>
<tr>
<td>Mechanical Room</td>
<td>125</td>
</tr>
<tr>
<td><strong>TOTAL (excluding balcony):</strong> 724 square feet</td>
<td></td>
</tr>
<tr>
<td>Balcony</td>
<td>125</td>
</tr>
<tr>
<td><strong>TOTAL (including balcony):</strong> 968 square feet</td>
<td></td>
</tr>
</tbody>
</table>

*Fig. 54 - Square Footage Breakdown Per Housing Unit*

It was found to be most efficient to place the "legs" of the structure at the vertices of the space frame. The lines of force though these legs flow though the
center of mass, as illustrated below. The main entry is from the back of the unit, via a ramp/staircase mechanism. One enters though a sliding door and walks up a staircase to the main floor living area. From there, the bedroom loft is accessed via a ship ladder and the balcony is accessed through a curtain wall doorway, as illustrated. Lots of windows are provided for ventilation. Due to the spherical shape of the gyroscopic window frame, each porthole window can be positioned to an appropriate direction, to capture the wind. The high ceiling of the dodecahedron shape also helps to provide a comfortable high ceiling height for a tropical environment setting.
The Approach

In doing this design, I threw away any pre-conceived notions about what a dwelling could or should be – and started from scratch. Inspired by the geometric shape of a dodecahedron \textit{(which is a Platonic solid)}, I chose to use vertices to connect from, rather than walls.

A Platonic solid is a polyhedron that is, in essence, a regular polygon. The faces of a Platonic solid are regular polygons, with an equal number of faces that meet at each vertex. All its edges are congruent, including its vertices and angles. Since a Platonic solid is a symmetric structure, it will allow for the minimum number of different parts to be used – ideal for the design of modular, pre-fab housing.

The plan was designed with great detail – for strength, part interchangeability, and with a view to use the minimum number of types of parts that could be used in different ways. This will be a portable structure that can be assembled and disassembled by hand and will be essentially a kit of parts, with multiple configurations. This design is based on a single unit configuration, however the
basic structure can also be configured into clusters of multiple dwelling units.

The building is adaptable, so that it may be used in different environments. The insulation for this particular building is designed for a tropical environment. It has cross-ventilations from every side. However, it will also be possible to create alternative versions for other climate types, using a similar framing — but with alternative ventilation and heating systems. For example, in colder climates, the panels may be interchanged for ones with more insulation.

Documenting each and every nut and bolt is typically not necessary for architectural designs, as this level of information is usually presented as details. However, it is important here for two reasons: firstly, the sequence of assembling these "nuts and bolts" is very critical and needs to be documented and, secondly, these "nuts and bolts" need to be simulated — at least structurally — to confirm that the system works well as a whole, especially given the minimalist nature of the building system.

**Design Features**

A space frame is used as the primary structural element. The space frame structure is thought to be a good fit, given the symmetric dodecahedron shape. Due to the dodecahedron shape, the floors, wall panels and hinges connect to the space frame structure via vertices. The vertex component is used to attach the stock framing bars for the space frame. The electrical system wiring is
concealed within the framing bars. For larger multi-unit arrangements, the fresh water pipes can also be routed through the framing bars, as well.

The walls are lightweight (fiberglass with aluminum reinforcements) and do not act as structural supports. Nor do they act as sheer walls. The external wall panels attach to each other, to form the dodecahedron shell. This shell encloses the space frame.

A "gyroscopic" window was developed, where a porthole window lies within a truncated spherical section that frames the window. This spherical window frame is assembled within a panel wall opening and can be rotated up/down or sideways, to achieve the best possible view. The window pane pivots within the spherical frame — to open and close the window.

Many of the components are used in different ways, so as to minimize the number of different parts. The framing bars, nuts and bolts are stock, but everything else was designed from scratch. The footers that are used for coupling the spare frame legs to the foundation are also used for ceiling supports, for example, with a different insert.

Although the main entry staircase with integrated ramp and balcony are stowable, they are intended to be left open most of the time, except during stormy weather. The main entrance has a sliding door which can be locked for security. The balcony is not accessible from the ground level and has a doorway that is part of a curtain wall system.

The mechanical components — such as the HVAC air handling unit, water heater and electrical panels — are placed in the lowest part of the space frame structure, beside the main entry interior staircase.

The space frame structure couples to a foundation concrete slab, using custom designed footers. These footers have optional hardware that can attach the footer to a set of cables. The cables rest below ground and serve to keep the legs from spreading out. This can be a useful feature when the unit is assembled for a temporary period of time and a concrete foundation is impractical or impossible.

The various components that make up the kit of parts and the Bill of Materials are illustrated in the following exploded views and the Bill of Materials list.
Plans

Fig. 59
Elevations & Sections

Fig. 60
Modular Components – Kit of Parts

Floor Stabilizer Assembly

Ceiling Support Assembly

Foundation Footer & Optional Cable Connectors

Panel Sealing U-Gasket

Structural Frame

Ceiling Support Hardware

Hinge Hardware

Sliding Door Assembly

Vertex 6 Leg Clamshell – for attaching interior panels and other interior components

Vertex 5 Leg Clamshell – for leg supports

Porthole Window Assembly – 36 inch diameter

Gyroscopic Window Assembly – 60 inch diameter

Fig. 61
Modular Components – Features

**Fig. 62**

- **Balcony Shutter Procedure**
  1. Open Normal Position
  2. Railings Removed
  3. Balcony Raised

- **Main Entrance Shutter Procedure**
  1. Open Normal Position
  2. Main Entry Door Closed
  3. Railings Removed

- **Main Entrance Assembly - Sliding Door**

- **Main Entrance Assembly - Entry Ramp**

- **Curtain Wall Assembly**

- **Balcony (Draughter) Assembly**

Nick Marinos
Frame

**Fig. 64 - Skeleton Frame**

**Fig. 65 - Skeleton Frame**
Interior

Fig. 66 - Living Room

Fig. 67 - View of Loft
3D Views

Fig. 68 - View – Inside Look

Fig. 69 - View – Inside Look
Climate & Location Adaptability

Fig. 70 - Country Image – Rear View

Fig. 71 - Desert Image – Rear View
### Bill of Materials

*(Sheet #1 of 4)*

<table>
<thead>
<tr>
<th>Item</th>
<th>Part Number</th>
<th>Thumbnail</th>
<th>Unit QTY</th>
<th>QTY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Framing.Bar</td>
<td>![Image]</td>
<td>Each</td>
<td>30</td>
</tr>
<tr>
<td>2.</td>
<td>Vertex_Trip_Clamshell_Derived</td>
<td>![Image]</td>
<td>Each</td>
<td>20</td>
</tr>
<tr>
<td>3.</td>
<td>Framing.Bar_Front_Leg</td>
<td>![Image]</td>
<td>Each</td>
<td>2</td>
</tr>
<tr>
<td>4.</td>
<td>Framing.Bar_Back_Leg</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>5.</td>
<td>Framing.Bar_Side_Leg</td>
<td>![Image]</td>
<td>Each</td>
<td>2</td>
</tr>
<tr>
<td>6.</td>
<td>Floor_Plate</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>7.</td>
<td>Foster_Frame_Joint</td>
<td>![Image]</td>
<td>Each</td>
<td>6</td>
</tr>
<tr>
<td>8.</td>
<td>Foster_Ball_Joint_Aos</td>
<td>![Image]</td>
<td>Each</td>
<td>5</td>
</tr>
<tr>
<td>9.</td>
<td>Foster_Ball_Joint_Base</td>
<td>![Image]</td>
<td>Each</td>
<td>6</td>
</tr>
<tr>
<td>10.</td>
<td>ANSI_B18.2.1 - 1-Ball</td>
<td>![Image]</td>
<td>Each</td>
<td>6</td>
</tr>
<tr>
<td>11.</td>
<td>ISO_Z40 - A - 24 x 100</td>
<td>![Image]</td>
<td>Each</td>
<td>6</td>
</tr>
<tr>
<td>12.</td>
<td>Foster_Collar</td>
<td>![Image]</td>
<td>Each</td>
<td>10</td>
</tr>
<tr>
<td>13.</td>
<td>Foster_Cable_Collar</td>
<td>![Image]</td>
<td>Each</td>
<td>10</td>
</tr>
<tr>
<td>14.</td>
<td>ANSI_B18.2.2 - 1/2 x 4</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>15.</td>
<td>Unit_Assembly_Harness1</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>16.</td>
<td>Unit_Assembly_Harness2</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>17.</td>
<td>Unit_Assembly_Harness3</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>18.</td>
<td>Unit_Assembly_Harness4</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>19.</td>
<td>Unit_Assembly_Harness5</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
<tr>
<td>20.</td>
<td>Vertex_with_5_Leg_Clamshell</td>
<td>![Image]</td>
<td>Each</td>
<td>5</td>
</tr>
<tr>
<td>21.</td>
<td>ANSI_B18.2.1 - 3/4-10 UNC - 8</td>
<td>![Image]</td>
<td>Each</td>
<td>24</td>
</tr>
<tr>
<td>22.</td>
<td>Framing.Bar_for_front_Floor</td>
<td>![Image]</td>
<td>Each</td>
<td>9</td>
</tr>
<tr>
<td>23.</td>
<td>Framing.Bar_for_rear_Floor</td>
<td>![Image]</td>
<td>Each</td>
<td>1</td>
</tr>
</tbody>
</table>

*Fig. 72*
## Bill of Materials

(Sheet #2 of 4)

<table>
<thead>
<tr>
<th>Item</th>
<th>Part Number</th>
<th>Thumbprint</th>
<th>Unit QTY</th>
<th>QTY</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>Vertex with 6 Long Chasms</td>
<td>Each</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>Ceiling Bar for 2nd Floor</td>
<td>Each</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>ANSI B1A.1.1-7/8 UNC - 6.5</td>
<td>Each</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Ceiling Bar for 2nd Floor</td>
<td>Each</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Roof Plate 2nd Level</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>Roof Plate 2nd Level Rear</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>ANSI B1A.2.1-2 1/2 UNC - Regular Type B</td>
<td>Each</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>Ceiling Bar for front edges 2nd Floor</td>
<td>Each</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>Floor Ball Joint Base</td>
<td>Each</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>ANSI B1A.2.1-1/2-13 UNC - 6</td>
<td>Each</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>Ceiling Joint Floor Base</td>
<td>Each</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>ANSI B1A.2.1-7/8-14 UNC - 6.5</td>
<td>Each</td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>Framing Bar for end 2nd Floor rev2</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Floor Ball Joint Axis Short</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>39</td>
<td>ANSI B1A.2.1 - 7/8-9 UNC - 1.5</td>
<td>Each</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>40</td>
<td>Framing Bar for front Rear Short</td>
<td>Each</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>41</td>
<td>Roof Plate 1st Level Connector</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>Panel with Round Window</td>
<td>Each</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>Panel with No Window</td>
<td>Each</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Panel with 4 Round Windows</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>45</td>
<td>Window Plate 40 inch Inner Subassembly Derived</td>
<td>Each</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Window Plate 40 inch Siding Ring</td>
<td>Each</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>47</td>
<td>Window Plate 40 inch Siding Ring</td>
<td>Each</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>ANSI B1A.2.3 - 3/8 - 26 - 3/16</td>
<td>Each</td>
<td>96</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 73**
### Bill of Materials

*(Sheet #3 of 4)*

<table>
<thead>
<tr>
<th>Item</th>
<th>Part Number</th>
<th>Thumbnail</th>
<th>Unit</th>
<th>QTY</th>
<th>Item</th>
<th>Part Number</th>
<th>Thumbnail</th>
<th>Unit</th>
<th>QTY</th>
</tr>
</thead>
<tbody>
<tr>
<td>49</td>
<td>Window_Continue_53_inch_Asymmetry_Derived</td>
<td>Each</td>
<td>4</td>
<td></td>
<td>61</td>
<td>ANESI/2H-3.21 - 7/16-20 UNC - 0.625</td>
<td>Each</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>Panel_with_Interface_to_Drawbridge</td>
<td>Each</td>
<td>1</td>
<td></td>
<td>62</td>
<td>ANESI/2H-3.21 - 7/16-20 UNC - 1.5</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>51</td>
<td>Panel_with_Recessed_Door_Frame_V0</td>
<td>Each</td>
<td>1</td>
<td></td>
<td>63</td>
<td>Inner_Plate_1st_Lvl_Williams_Marine_Railing</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>52</td>
<td>Panel_Drawbridge</td>
<td>Each</td>
<td>1</td>
<td></td>
<td>64</td>
<td>Inner_Door_Glass_Door_Derived</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>53</td>
<td>Panel_Drawbridge_Pin</td>
<td>Each</td>
<td>1</td>
<td></td>
<td>65</td>
<td>Inner_Door_Frame</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>54</td>
<td>ADTH/P08 - 3/4</td>
<td>Each</td>
<td>2</td>
<td></td>
<td>66</td>
<td>Door_Guide_Ball_Larkin</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>55</td>
<td>ADTH/P08 - 1/4 x 3/4</td>
<td>Each</td>
<td>2</td>
<td></td>
<td>67</td>
<td>ANESI/2H-3.21 - 3/4-20 UNC - 8</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>56</td>
<td>Panel_Drawbridge_Cabinet</td>
<td>Each</td>
<td>1</td>
<td></td>
<td>68</td>
<td>Drawbridge_Frame</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>57</td>
<td>Drawbridge_Exterior_Pin</td>
<td>Each</td>
<td>1</td>
<td></td>
<td>69</td>
<td>Drawbridge_Pin</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>58</td>
<td>Drawbridge_Exterior_Lock_Pin</td>
<td>Each</td>
<td>2</td>
<td></td>
<td>70</td>
<td>Shipbinder</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>Panel_Drawbridge_Exterior_Railings</td>
<td>Each</td>
<td>4</td>
<td></td>
<td>71</td>
<td>Ruler_Rule_1st_Lvl_Railing</td>
<td>Each</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>Ruler_Rule_1st_Lvl_Front</td>
<td>Each</td>
<td>1</td>
<td></td>
<td>72</td>
<td>Ruler_Rule_1st_Lvl_Rail_Railing</td>
<td>Each</td>
<td>1</td>
<td></td>
</tr>
</tbody>
</table>

*Fig. 74*
Bill of Materials
(Sheet #4 of 4)

![Bill of Materials Table]

**Fig. 75**
Conclusions

Significant research was done to identify pre-fab construction design precedents. In addition to the summary analysis presented here, extensive time was spent exploring software solutions, so as to efficiently design, evaluate, and document building systems such as this. The ability to seamlessly exchange information between architectural, structural, MEP, and environmental design and evaluation software was found to be very important in order to produce a project of this type, and in such a short period of time. Building Information Systems (BIM) software fits very well here, but with the added complexity of dealing with issues at an engineering level.
## Table of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Thesis Design - Space View</td>
<td>10</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Maison Tropicale - Conceptual Sketch</td>
<td>9</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Brazzaville Version - Sites, Plans &amp; Elevations</td>
<td>10</td>
</tr>
<tr>
<td>Figure 4</td>
<td>Maison Tropicale - Brazzaville Version - Plan</td>
<td>11</td>
</tr>
<tr>
<td>Figure 5</td>
<td>Maison Tropicale - Brazzaville Version - Section</td>
<td>11</td>
</tr>
<tr>
<td>Figure 6</td>
<td>Maison Tropicale - Brazzaville Version - West Elevation</td>
<td>12</td>
</tr>
<tr>
<td>Figure 7</td>
<td>Maison Tropicale - Brazzaville Version - South Elevation</td>
<td>12</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Maison Tropicale - Transport &amp; Assembly</td>
<td>13</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Large Brazzaville Building in New York</td>
<td>13</td>
</tr>
<tr>
<td>Figure 10</td>
<td>Remaining Columns - Brazzaville Site</td>
<td>14</td>
</tr>
<tr>
<td>Figure 11</td>
<td>Exhibition at Tate Modern</td>
<td>14</td>
</tr>
<tr>
<td>Figure 12</td>
<td>Eames House - Site</td>
<td>15</td>
</tr>
<tr>
<td>Figure 13</td>
<td>Eames House - Bridge Plan vs. Current Plan</td>
<td>15</td>
</tr>
<tr>
<td>Figure 14</td>
<td>Eames House - Plans &amp; Elevations</td>
<td>16</td>
</tr>
<tr>
<td>Figure 15</td>
<td>Eames House - Structural Grid</td>
<td>17</td>
</tr>
<tr>
<td>Figure 16</td>
<td>Eames House - Structural Framing</td>
<td>17</td>
</tr>
<tr>
<td>Figure 17</td>
<td>Eames House - Living &amp; Working Spaces</td>
<td>17</td>
</tr>
<tr>
<td>Figure 18</td>
<td>Eames House - Climate Data</td>
<td>18</td>
</tr>
<tr>
<td>Figure 19</td>
<td>Eames House - Climate Data</td>
<td>19</td>
</tr>
<tr>
<td>Figure 20</td>
<td>Farnsworth House - Site</td>
<td>20</td>
</tr>
<tr>
<td>Figure 21</td>
<td>Farnsworth House</td>
<td>20</td>
</tr>
<tr>
<td>Figure 22</td>
<td>Farnsworth House - Exploded Structural Components</td>
<td>21</td>
</tr>
<tr>
<td>Figure 23</td>
<td>Farnsworth House - Structural Details</td>
<td>22</td>
</tr>
<tr>
<td>Figure 24</td>
<td>Farnsworth House - Plan</td>
<td>22</td>
</tr>
<tr>
<td>Figure 25</td>
<td>Farnsworth House - Section</td>
<td>23</td>
</tr>
<tr>
<td>Figure 26</td>
<td>Farnsworth House - South Elevation</td>
<td>23</td>
</tr>
<tr>
<td>Figure 27</td>
<td>Farnsworth House - Climate Data</td>
<td>24</td>
</tr>
<tr>
<td>Figure 28</td>
<td>Habitat '67 - General View of West Side</td>
<td>25</td>
</tr>
<tr>
<td>Figures 29-31</td>
<td>Habitat '67 - Plans, Sections 7 Elevations</td>
<td>26</td>
</tr>
<tr>
<td>Figure 32</td>
<td>Habitat '67 - Exterior View</td>
<td>27</td>
</tr>
<tr>
<td>Figure 33</td>
<td>Habitat '67 - City View</td>
<td>27</td>
</tr>
<tr>
<td>Figure 34</td>
<td>Ramot 1 Housing Complex - Exterior View</td>
<td>28</td>
</tr>
</tbody>
</table>
Figures 35-38  Ramot 1 - Dodecahedron Structure, Site, Hand/Leaf Metaphor
Figures 39-41  Ramot 1 - Plans, Sections & Elevations, Site Illustration
Figure 42  Hypothetical Project Site – Description and Analysis
Figures 43-46  Scout Key - Site/Location
Figure 47  Scout Key - Climate Data
Figure 48  Window Overhangs
Figure 49  Indoor Air Motion
Figure 50  Natural Ventilation
Figure 51  West-facing Glazing Minimized
Figure 52  Use of Plants for Shade
Figure 53  Efficient Design
Figure 54  Square Footage Breakdown Per Housing Unit
Figure 55  Lines of Force through Center of Mass
Figure 56  Circulation and Ventilation
Figure 57  Platonic Solids
Figure 58  Tropical Climates
Figure 59  Plans
Figure 60  Elevations & Sections
Figure 61  Modular Components - Kit of Parts
Figure 62  Modular Components - Features
Figure 63  Renderings
Figures 64-65  Frame
Figures 66-67  Interior - Living Room and View of Loft
Figures 68-69  3D Views - Inside Look
Figure 70  Climate & Location Adaptability - Country Image - Rear View
Figure 71  Climate & Location Adaptability - Desert Image - Rear View
Figures 72-75  Bill of Materials
Figure 76  Dockyard Image

1 Marinos, Nick — Images created and regenerated, using Google Earth & Maps.
8 Marinos, Nick — Images created, using Climate Consultant software.
9 Marinos, Nick — Table & images created.
10 Marinos, Nick — Design.


---

Fig. 76 - Dockyard Image