Portable Housing
An Exploration Into Lightweight Housing for Remote Scientific Research

By Keith V. McCluskey

Boston College

Submitted to the Department of Architecture in Partial Fulfillment of the Requirements for the Degree of Master of Architecture at the

Massachusetts Institute of Technology, June 2002

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Abstract

This thesis proposes the design of portable housing for use in scientific research applications in remote locations. Currently, remote research is conducted from tents or other portable shelters. Larger, more hospitable structures are often too heavy or bulky to carry to these locations. This thesis proposes a shelter that is lightweight, packable, and biodegradable.

The shelter is constructed of cardboard panels, which can easily be left to decompose in most environments, or can be recycled after use. The shelter is meant to last only for one season (up to six months), and then be recycled. The shelter requires upkeep on a weekly basis to maintain its waterproofness, and responds to the climatic changes of its surroundings by opening or closing as temperature and conditions warrant. It is, hopefully, much more livable than a tent.

Thesis Supervisor: Bill Hubbard Jr.
Title: Adjunct Associate Professor of Architecture
Acknowledgements

This thesis would not have been possible without the help and support of many, many people. First and foremost, my parents and sister deserve more credit than can be expressed here. Their patience and support, in every possible way, have helped me to keep going even when things have been at their most difficult. They have always supported me, and urged me to pursue my dreams and desires, doing everything possible to help me through. They have made the load much lighter, and the rewards much greater, than they otherwise would have been. I am constantly reminded that I am very lucky to have this support, and am incredibly grateful for it.

My thesis committee also deserves a great deal of thanks. I chose my committee not just for their disparate strengths (landscape architecture, construction and prototyping, and design), but also because of their personalities. All three are no-nonsense, and very willing to help. This maturity and support was very welcome, and helped make this work possible.

Finally, I must express a tremendous debt of gratitude to the head of my committee, my advisor and friend Bill Hubbard. His was the first studio I took, back in the fall of 1996. It seems only fitting that he should be the advisor to my final school project. His enthusiasm is contagious, and his breadth of knowledge is amazing. His commitment to his students is unmatched. He helped me cultivate a love of design six years ago, starting me on the road to becoming an architect. Now, at the end of an often difficult and sometimes dispiriting four-year program, he has helped renew my confidence in my design abilities, and rekindle my love of all things architectural. So, Bill, thanks so much. I might have been able to do it without you, but I doubt that I would have wanted to.
This isn't as crazy as it looks

PORTABLE MOUNTAIN HOUSING
A thesis by Keith McCluskey

Produced written modeled and built by Keith McCluskey

MAY 16 2002 - SOUTH CORNER
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Introduction: Beginnings

An explanation of where this thesis came from

I have always enjoyed hiking and camping. I grew up in the Adirondack Mountains, and have hiked and camped many times. In my four years of graduate school, I have spent at least some part of each spring break sleeping outside.

As an architect and designer, my greatest successes have always come with works at a small scale. The closer I can get to full scale, the better the design ends up, and the more fun it is to design. 600,000 square foot convention centers are not things I have any interest in designing. From the scale of the residence on down, I begin to really enjoy design, since I can get into the details, building them at close to full scale.

It seemed like an easy step, then, to choose a thesis topic that combined those two things. By choosing a topic that involved small wilderness shelters, the thesis, I hoped, would allow me to hit on both these topics. It would hopefully also engage my love of construction, and be a project that could be discussed in terms of ecologically sound materials.

But this thesis began as something a bit different than it ended up, as evidenced by the text of my original thesis proposal:

PORTABLE HOUSING
An effort to create portable housing for mountainous regions

Mountainous housing in remote regions has traditionally been of this type: bulky buildings made with an inefficient use of materials. In log homes, for example, a good deal of timber is used to build the houses. Forests are clear-cut, and the resulting timber is used to make the houses. This is inefficient, ugly, and not environmentally sound.

The Appalachian Trail is one of the United States greatest natural resources. It is several hundred miles of wonderful wilderness trail, through breathtaking landscape. To build housing along it like previous mountain housing efforts would be
Each year, more than thirty people traveling along the trail die as a result of exposure, accident, or catastrophe. Hundreds are injured. And finding help along the trail can be a daunting task. Passing hikers can provide some help, and the trail does intersect several state parks, with their contingents of park rangers, and ridge runners, but a set of trail stewards who work specifically at safeguarding those who walk the trail might be an improvement. This thesis proposes the creation of that group of stewards, and with that, housing for those stewards.

This thesis is challenged on two levels. First, on the social level: Does the Appalachian Trail warrant such a group of stewards? Would the Appalachian Trail Conference, the Trail's governing body, want, or be able to afford, stewards? Would they be able to coordinate the logistics of putting them in place? And would they agree that stewards are a help on the trail, and not a detriment or a distraction? Would the work of the stewards not simply duplicate that of the ridge runners?

This challenge is really secondary. If the Appalachian Trail is not the appropriate site, there are certainly dozens of other regions where ultra-lightweight housing would be of benefit. Mountainous regions around the world would benefit from housing that is portable by people, and is quickly and easily assembled and disassembled, leaving virtually no trace.

This leads to the second, and perhaps more primary, challenge of the thesis. If there are to be Trail stewards, they will be required to live on the trail for the greater part of the year, in some very harsh climates. Their housing will have to meet several strict requirements:

- Incredible lightness: The housing must be able to be carried on the backs of hikers - each segment must be of a size (2'x4' max) and weight (30 # max) that can be easily handled by a hiker.

- Ease and speed of assembly: The housing must be able to be built or unbuilt in the space of a day.

- Stealth: The building, once disassembled, must leave virtually no trace. No foundation, no clear-cutting of timber, no excavation. While it stands, it must not be a distraction on the trail.

- Climatic concerns: The trail is a harsh environment. The structure must withstand wind, rain, cold, and snow. The space must also be heated to some degree, and thus insulated to conserve heating resources.

- Livability: The space must be accommodating enough that someone can live in it for six months of the year, year after year. It cannot be a simple tent.

The avenues of research and methodology for this thesis will be several. First, a study must be made of the Appalachian Trail, and the people who are a part of it: its governing body and the many who use it each year. Studies of rates of injury and death, and studies as to whether or not stewards would alleviate any of that must be undertaken. Where would these stewards be placed so as to be most effective?

Studies then must be made into the appropriate structure, and its design. Tent prototypes are one option. But by no means is the tent the only option. Domes and transportable panel systems must be studied against tensile structures, to see which yields the best result for the least weight.

Details of the structure must then be hashed out. The house prototype must be designed, and it should hopefully go beyond a one-room tent or shack. View, light and spatial considerations must be considered. The space must be designed in such a way that someone would willingly live there for nine months, and several years on end, earning a relatively low wage.

Studies must be conducted into the appropriate materials and costs. New composite materials certainly suggest themselves for their lightness, but are they environmentally sound? Is
Shigeru Ban's cardboard and paper tube architecture a possibility? Which material has the best insulative properties relative to weight?

Once material decisions have been made, the prototype must be designed, down to the nuts and bolts. Details must be designed to facilitate ease and speed of construction. The fasteners themselves become an issue. Boxes of heavy nails and screws are probably not the best option. It is my hope that the structure will integrate some of the furnishings of the space, to allow yet again for fewer and lighter trips to the site.

Once this is done, an attempt will be made to build the structure, if not in its entirety then in some collection of details. Full-scale models will very much allow a test of the ultimate proposition of the thesis, that it must be very light.

This thesis, if successful, will have covered almost all of the areas that interest me architecturally: sustainability and environmentally sound design, new material types, design and prototyping of components and parts, and the assembly of buildings. Most importantly, it will challenge me as a designer: can I create a building that is well enough designed that it is not a distraction to the hikers on the trail, while allowing the occupant some measure of civilized and comfortable living? Most importantly, can I make architecture exist, high in some remote part of some mountain trail?

After discussions with several people, including Chris Carbone of the Building Technology department, it was determined that the Appalachian Trail did not need additional stewards. Chris had worked for a few years as a ridge runner, and said that the idea of additional stewards was redundant. Compounded with the additional problem of getting permits for any type of construction on the trail, Chris suggested that I look elsewhere for a vehicle for my thesis. He suggested that this type of housing would be ideal for scientists doing long-term research in the wild. Both advisors, Kimo and Bill, suggested this would be a sound idea, since it would allow more character to be imbued into our fictional occupant, since a scientist has obvious tasks and spatial and programmatic needs. And so, two weeks into the thesis semester, the change was made.
PORTABLE HOUSING
An effort to create portable housing for mountainous regions

Mountainous housing in remote regions has traditionally been of the type seen on the left, below: bulky buildings made with an inefficient use of materials. In the examples provided, a good deal of timber was used to build up the houses. Forests were clear cut, and the resulting timber was used to make the houses. This is inefficient, ugly, and not environmentally sound.

The Appalachian Trail, shown on the left, is one of the United States' greatest natural resources. It is several hundred miles of wonderful wilderness trail, through breathtaking landscape. To build housing along it of the type below would be to ruin it.

Yet each year, more than thirty people traveling along the trail die as a result of exposure, accident, or catastrophe. Hundreds are injured. And finding help along the trail can be a daunting task. Passing hikers can provide some help, and the trail does intersect several state parks, with their contingents of park rangers, but there is no set of trail stewards who work specifically at safeguarding those who walk the trail. This thesis proposes the creation of that group of stewards, and with that, housing for those stewards.

STUDIES OF ANCIENT TENT PROTOTYPES

Figure 1: Original thesis document, page 1.
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This thesis, if successful, will have covered almost all of the areas that interest me architecturally: sustainability and environmentally sound design, new material types, design and prototyping of components and parts, the assembly of buildings, etc. Most importantly, it will challenge me as a designer: can I create a building that is well enough designed that it is not a distraction to the hikers on the trail, while allowing the occupants some measure of civilized and comfortable living? Most importantly, can I make architecture exist, high in some remote part of some mountain trail?

Figure 2: Original thesis document, page 2.
Chapter One: Purpose

Research into spaces a scientist could use

After deciding on designing a shelter for a scientist, it became necessary to do research into the needs of a scientist in the wild. The initial inspiration for scientists in the wild came from the New York Times Magazine, in an article entitled “George Divoky’s Planet”. George Divoky is an ornithologist who has been studying a group of guillemots and their relation to global warming on Cooper Island in the Arctic for the past thirty years. 1 He lives in a simple tent, and has a rough shelter, called the weatherport, which he and his assistant share, since using only tents for four months is uncomfortable.

![Figure 3: George and Tamara in the weatherport. (Image courtesy of the New York Times magazine)](image)

This article was inspirational in that it showed that there were people doing research who could potentially use this shelter.

1 Frey, p. 26
The original idea was to create a shelter and place it in New Hampshire, since the AT was close there and could be easily visited. Also, since I had decided on using biodegradable materials, and cardboard became the chosen material, New Hampshire seemed a good fit since it is one of the leading states in pulp and paper manufacture.

Chris Carbone suggested I contact someone he knew who did those kinds of research at Dartmouth. Our schedules didn’t mesh, but he put me on to the Hubbard Brook Research Forest, in northern New Hampshire. I was lucky enough to speak with Ralph Perron, a researcher there. He very generously set up a time for me to come visit the Forest, and scheduled my trip to coincide with the weekly gathering of data. I spent one lovely Monday morning hiking around Hubbard Brook with Ian Halm, another of the researchers there. Every Monday, all year round, the people at Hubbard Brook measure rainfall data, and flow data from all the creeks that flow into Hubbard Brook. Ian and I spent the morning hiking to about ten rainwater collection sites, and four different weirs, which measure flow in the creeks and streams. The collection of data is straightforward, and involves mostly pencil and notebooks. Ian suggested that someday the collection would all be digital, but the high prices prevented that now. Luckily for me I had chosen a day to visit when the weather was good. Often, Ian is hiking in rain, or snowmobiling and snowshoeing, collecting data in freezing temperatures. In the summer, the data collection all takes place while surrounded by biting insects.

Fig. 4 Hubbard Brook Research Forest. (Image courtesy of www.hubbardbrook.org)

After discussing my thesis topic with him for the better part of the morning, it became clear that there might be a use for my ‘cardboard house’. Ian suggested that it was rare for people to do scientific research for that long in the wild, and that it would most probably only be animal researchers who would want to be that far removed from civilization for that long. The idea of a shelter in which you could stand up, and have space for storage, definitely seemed better than six months in a tent, however. Ian had spent a summer in a tent doing research, and after a few months the tent had been bleached by the sun, smelled, and was generally unpleasant. Now, my shelter hasn’t been tested. It too may bleach and begin to smell, but at the very least it has room to stand up, and operable windows that allow ventilation.

Bolstered by this day of hiking and discussion with Ian and Ralph, I pushed on with the design of the actual structure.
and details. I am deeply grateful to them, and to Hubbard Brook, for their tremendous generosity in allowing me to visit and hike with them.

Figure 5: The view of Mount Washington from the south slope.

Figure 6: An initial sketch of the idea.
A good amount of research went into the design of the structural elements. Brainstorming sessions with my committee, discussions with the Building Technology faculty, and full-scale component testing allowed me to get to the point where this project is physically possible. For it to be made real, optimization and further testing would need to occur. But in only four months, to have gotten to the point of the idea being actually possible, is quite thrilling.

There are several areas of concern that were addressed in the structural analysis: the floor, which is the basis for the whole structure; the panel system, including the windows and joints; and the roof system, which ended up being a canvas panel.

Floor

The floor was the initial structural component that was discussed, since it is the basis and also originally was the packing system for the whole structure. Originally, the floor was folded into two pieces, and framed out like a backpack, allowing a space on the inside for transportation of materials. The panels were later flattened and the floor was to be supported by tension members. This was later changed, to allow the floor to match the wall panels and reduce the number of components and increase the number of assembly possibilities. The final rendition of the floor is supported by the same L-shaped beams as the walls. Made of corrugated cardboard, these beams are quite strong when glued along the seams.

The following images show the sequence of design ideas:
Figure 7: The first floor system.

Figure 8: Note the beams, which fold into a pack.

Figure 9: Second floor system.

Figure 10: Note the tension members and posts.
Figure 11: Original post for tension system.

Figure 12: Connection, post to floor.

Figure 13: Connection, full-scale mockup.
Figure 14: The final foot at full scale.

Figure 15: The mockup, exploded.

Figure 16: The clips.
Panels and Window

The panels were built in the same way as the floor, a tri-fold panel with dado cuts along the outside edges to take a spline. They were supported by the same L-shaped beams as were used on the floor. For details of this, see the assembly sequence. The three fold system is set at a size that fits on the back, and also expands to a comfortable interior height.

The panels differed from the floor in that they had to accommodate windows. The first window was prototyped in Kimo Griggs’ Computer Aided Design and Manufacture Class (see Appendix A). What follows are some images of the window prototype.

![Figure 17: Vacuum formed window and mold.](image)

![Figure 18: Window profile](image)
Figure 19: The window prototype, open for ventilation.

Figure 20: The window in the demonstration model.
The roof was the final piece of the design. Several ideas were explored using flat roofs, but these were deemed too heavy, not strong enough, or too difficult to erect. Finally, the idea of a canvas roof, with all its benefits, was adopted. The canvas allows breathability, is light, naturally softens the sunlight while illuminating the interior, and can be waterproofed. It was decided to tension two pieces of canvas opposite each other, to create a peak to shed water and to add strength. It also creates a section within the space. The roof is cable-stayed to the ground or surrounding trees, and is operable: it can be lifted in warm weather to allow even more ventilation.
Once canvas had been decided upon, it took on more uses. Instead of only having punched openings for light, canvas panels were used to cover part of one wall, above the sleeping area, to allow more light in. In the final design, these faced east and allowed in the morning light. Canvas is easy to attach with the sole building material, starch glue.

Figure 24: Canvas panels on the 1/3 scale model. Note the overhang of canvas, for shelter outside in warm months.

Figure 25: Initial sketch of the canvas panels.
Assembly and Component Pieces

Figure 26: Final assembly sequence renderings, hopefully self explanatory. All the pieces of cardboard – panels, splines, and L shapes - are assembled with starch glue. Metal feet, rods, and clamps, plastic windows, and canvas roof and panels add to the cardboard kit.
How does it get built?

1. ARRIVE. UNPACK
   
   FOLD OPEN FLOORS
   (SHOVEL FOOT AREA)
   
   SET FEET, W/ EACH PANEL
   GLUE AS YOU GO - NOT 100% NECESSARY.
   
1A. GLUE UP ALL COLUMNS/(IN. OUT) COUNT

   NIGHT

2. LOCK IN COLUMNS, LOCK IN LOWER WALL LIP - GLUE, BUT WILL HOLD.
   START TO UNFOLD WALLS
   STAND UP & GLUE - WHAT HELPS WHILE GUE DRIES?
   GET WALLS UP. GLUE, BUT WILL HOLD. WIND?
   GLUE IN י Canvas on one side
   ADD FRAMES AROUND TOP + WINDOWS (Canvas)

3. MUST BE STABLE TO ADD ROOF.
   ROLL OUT, CABLE DOWN.
   (POP-UP)

Figure 27: Assembly sequence sketch.
Figure 28: The component parts, all laid out, at full scale.

Figure 29: The relative size of the pack of components.
Figure 30: Diagramming the wall construction sequence.
Figure 31: An interior sketch, showing the placement of the columns.

Figure 32: The L-columns, used in the walls and floor.
Chapter Three: Cycles
Making a shelter that agrees with nature

One of the ideas of this project is that the occupant is more closely connected to the natural world through the shelter. This may sound like an outrageous idea, but it is meant only on the most simple level. The building is cyclical in nature: It exists with the seasons, being built up and taken down in six months from spring to fall. It requires weekly maintenance in order to maintain its waterproofness and soundness. This weekly work could be integrated with the weekly scientific work – two days to science, two days to the shelter and the site. And on a daily basis the cycle would be the same as any camping or hiking endeavor: getting water, cooking, doing the work, and so forth.

This cyclical relationship with the environment is very common in scientific research. For instance, at Hubbard Brook, every week the routine is the same. But every week there are different challenges that present themselves and must be addressed. Similarly in the wild, each week would have the same schedule, but each would play out differently depending on the circumstances encountered by the occupant. The basic weekly schedule would also involve one trip a week back to wherever the scientist came from, perhaps staying overnight, in order to restock supplies and drop off collected data.

There would also be a seasonal relationship with the site. As the occupant lives there, she could adjust the shelter to her needs. More windows could be added as views were found. And earthworks could be built up not only to protect the shelter from rainwater runoff, but also to create a space around the shelter, extending it into the outside. At the end of the season, the shelter would either be taken back, or left to decompose, depending on the environment. But the earthwork could remain, as a marker of the inhabitation, and as something that could be built on later.
Figure 33: Diagram of the weekly cycle.

Figure 34: Site model. Note the burm behind the shelter.

Figure 35: The shelter in the environment.
Figure 36: Initial ideas for window placement, to take advantage of views.

Figure 37: Window revision, with Bill's assistance.
Chapter Four: Futures

Other possibilities for the shelter

This project has come been designed primarily with the idea of scientific research. But clearly there are other applications where this shelter would be applicable, from disaster relief to military applications.

Within the realm of scientific research, the project has reached the level of the possible. With testing and optimization, the shelter could easily be realized. As a modular system, it is easily adaptable to other situations. It can be sized to fit whatever needs arise.

Figure 38: Diagrams of future possibilities.
The day of the final review came and, after a few solid weeks of very little sleep, everything was ready. The review, as a whole, went well. The critics offered tough, but fair, criticisms, asking questions on a variety of topics. A DVD of the review will be included at the end of this book.

The jurors, from left to right in the above picture: Bill Hubbard Jr., Advisor; Stanford Anderson, Department Head; Carol Burns; George Thrush; Kimo Griggs, Reader; Anne Spirn, Reader; Reinhard Goethert; and Marlon Blackwell.

What follows are the images from the final presentation.
Figure 40: Hardline drawings.
Figure 41: The 1/3 scale model.
Figure 42: A second look.
Figure 43: A montage of the model in nature.
Figure 44: The full scale model.
Figure 45: A second look.
Figure 46: A third look.
Figure 47: View from the inside, out.
Figure 48: The reasons why.
Appendix A: Computer-Aided Design and Manufacture

I would like to express my thanks to Kimo Griggs and Dan Schodek of the GSD for allowing me in his class, GSD 6319. I learned a tremendous amount about computer-aided manufacture, and this had a deep impact on my thesis. It was in this class that I developed the window ideas, and moved from the initial dome and panel idea to the idea of a folding panel, while paying close attention to ease of assembly.

DOME CONSTRUCTION PROTOTYPES

- Flat panel construction for ease of transportation
- Lightweight, biodegradeable materials - waxed paper skin and cellulose insulation
- Panels come attached as units for ease of assembly
- Vacuum formed or molded windows and oculus also break down into flat, stackable pieces
- Clip hangers allow for lightweight, easy assembly
- Domes are cable restrained from the inside to provide extra stiffness, resistance to uplift

Questions:
- Is this a habitable space? Would a different shape be more appropriate?
- Is it structurally strong enough? Will the connections hold?

Figure 49: The very early dome idea for the shelter. Many thanks to Kimo Griggs and Dan Schodek for steering me away from this.
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