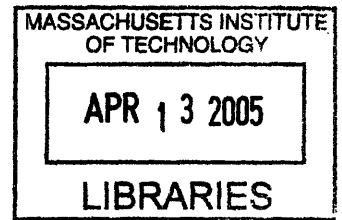


Temporary Shelter for the Homeless

by

Christine Lin



Submitted to the Department of Mechanical Engineering In Partial Fulfillment of the Requirements for the Degree of

Bachelor of Science




at the


Massachusetts Institute of Technology


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## ABSTRACT

A one-person cardboard structure was designed to temporarily shelter the homeless during harsh weather conditions. The overall form is based on the folding Yoshimura pattern. It is collapsible, wind and water resistant, and structurally rigid. The design is a prototype made from commonly available cardboard sheets and suggests how this material can be manipulated in future models.

Thesis Supervisor: David R. Wallace

Title: Esther and Harold E. Edgerton Associate Professor

## **Introduction**

In the cities of Boston and Cambridge, the homeless number 6,241 and 487 respectively, however, these are believed to be dramatic undercounts. These counts include 265 people who were on the street during the night of the each census, but many of the homeless do not wish to be found and thus remain hidden.<sup>1</sup> As in every city, there is simply not enough shelter space to accommodate the homeless. In the New England region, the winter months are especially of concern as temperatures consistently drop below freezing. Also, in contrast to New York City and Philadelphia, Boston has no laws allowing public officials to force the homeless into emergency shelters. Thus, the homeless who prefer not to stay in shelters for a variety of valid reasons must somehow find a way to keep warm. Even finding a reasonable place to sleep has become a difficult endeavor. With new park benches, bus shelters, and heating vents touting designs that inhibit a comfortable horizontal position, very few options are left for the homeless besides doorways and bridges.

In Boston, hundreds of homeless people avoid the shelter system, and thus an estimated eighteen to twenty-four homeless people die each year from the city's extreme cold weather.<sup>2</sup> This thesis seeks to develop a provisional shelter that will offer a level of

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<sup>1</sup> City of Boston Emergency Shelter Commission, "Homelessness in the City of Boston, Winter 2003-2004." 8 December 2003.

City of Cambridge Department of Human Service Programs, "Cambridge Homeless Census—March 29-30, 2004," 15 April 2004.

<sup>2</sup> "Out in the cold: should Boston force homeless people indoors in cold weather?" Looksmart Current Events, 21 March 2003, available from [http://www.findarticles.com/p/articles/mi\\_m0EPF/is\\_22\\_102/ai\\_99146993](http://www.findarticles.com/p/articles/mi_m0EPF/is_22_102/ai_99146993).

protection for these people during harsh weather. Because of the short time frame and nature of the work, it focuses on temporarily alleviating the situation of the homeless to prevent death and cold-related health problems rather than on tackling the root causes of the problem. Specifically, the goal is to design and build a light and portable temporary structure for one person that will resist wind and precipitation while taking into account mass production and distribution for the poorest of markets.

## **Background**

At first, the general idea was to create a product for the homeless that would alleviate their situation. To further define this, interviews were conducted on October 23, 2004 with two middle-aged homeless men in Harvard Square. The purpose of these interviews was to determine why there are homeless who choose to stay on the streets as opposed to shelters, what these people currently do to stay warm, and what, if anything, could be created to alleviate their situation. Extensive research was also performed on existing efforts and projects that address the homeless problem, and the most relevant and successful are noted here.

Rich can be found sitting outside the CVS in Harvard Square on most days. He spends the night close by in the doorway of the Harvard COOP. He has lived through five winters in Cambridge and makes do with an old sleeping bag. Passers-by sometimes hand him coats, gloves, or hot food. Rich stays out of the shelters because “people who go there aren’t usually a very good class of people: troublemakers, drunks, loudmouths.”

Additionally, there are racial rivalries that make them unsafe. Shelters are also understaffed, and governmental budget cuts have dramatically decreased the number of beds. What Rich would really like is a sub-zero sleeping bag so he could just “climb in there and be warm”, but he would settle for any “warm, safe place to sleep”.

Bob can usually be spotted down the street from Rich, walking back and forth along the median with a cardboard sign. He taught me an important lesson through my many attempts to secure an interview with him—even the homeless need to be paid for their time. Bob has been homeless for four years but has spent only one year in the Boston area. With two other homeless men, he lives under a bridge where they have a radio to listen to the Sox games, some candles, blankets, and batteries among their possessions. They use a tarp to keep things dry, but when that does not work, two meals must be sacrificed to pay for dryer time at the Laundromat. Still, living under a bridge is preferred to living in the shelters, which Bob refers to as “awful places” because of overcrowding, unequal treatment, dirtiness, and corruption. However, to him, a luxury is being able to take a shower at the shelter three times a week. He considers it very lucky if he can collect forty dollars in one day. When I asked what he could be given to make life a little easier, Bob replied, “Besides money, I don’t know, money’s what makes the world go round.”

Indeed, what helpful product can be handed out to the homeless when they lack life’s basic necessities? My Brother’s Keeper Quilt Group, started in 1982 by Flo Wheatley, distributes thousands of homemade sleeping bags, stitched from discarded fabrics, to the

homeless every year.<sup>3</sup> Donated clothing and blankets are not too difficult to procure, however, they have a limited capacity to retain warmth under windy and wet weather conditions. ParaSITE is a project by the artist Michael Rakowitz that uses a building's HVAC ducts to inflate structures costing about five dollars and made mostly of polyethylene, the same material used for trash bags. As of early 2004, thirty of these personally designed shelters were in use and functioned dually as a visual protest against cities' attempts to hide and drive out their homeless populations.<sup>4</sup> The customization involved in some of the units to attach to hot air vents and the necessity of those vents for use of the shelter perhaps limits their mass production. Refuge Wear by Lucy Orta and The Homeless Vehicle Project by Krzysztof Wodiczko are two other well-known projects by artists that address the homeless situation, but similarly to paraSITE, they are not designed for mass production and distribution but rather as a tool for dialogue.

From the interviews conducted and the precedents researched, it was determined that a form of shelter with some structural rigidity and protection against wind and precipitation would be useful to the homeless population living outside on the streets. The shelter would also have to be practical and easily mass produced in order to achieve maximum benefit and usefulness.

### **Definition of Problem**

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<sup>3</sup> Celeste Mitchell, "My Brother's Keeper," Family Circle, 21 November 1995.

<sup>4</sup> Michael Rakowitz personal webpage, available from <http://www.possibleutopia.com/mike>.

The needs determined from the interviews and precedents were further developed in specificity with regard to material performance in outdoor conditions, cost, size, weight, form, safety, and environmental impact. Although limiting outdoor weather conditions are specific to Boston, thousands of homeless in other cities, such as New York City, face similar conditions and have similar needs.

In Boston, the average low temperature dips below freezing from December to March,<sup>5</sup> and this does not include wind chill, which often makes the temperature feel well below zero and most harmfully, increases the likelihood of cold-related sickness and death. Throughout the year, the city receives between three to four inches of precipitation per month. Thus, the shelter must have both wind and water resistance, as well as provide some thermal resistance to trap the user's body heat. It also needs to provide a layer of protection between the user and the ground since much body heat can be lost through conduction.

Because the homeless struggle to find even enough money for food, the cost of the shelter must be inexpensive enough to distribute freely and for a non-profit, or comparable organization, to fund. For an initial run of three hundred units for the city of Boston, five dollars is a reasonable maximum cost.

Because homeless people do not have a permanent or secure place of residence to leave possessions, the shelter must be lightweight and portable. It cannot weigh more than ten

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<sup>5</sup> The Weather Channel, available from <http://www.weather.com>.

pounds or occupy more than two feet cubed in its inactive state. This will reduce costs in the shipping of the product. It also requires an easy and ergonomic method of transportation by the user, and must be easy to assemble with one person. Additionally, modularity is important because the homeless are not always companionless. This will allow for units to be combined in different ways to accommodate for multiple persons within a single enclosure. For a single unit, the interior space must be comparable to that of a one-person tent (see Table 1).

Product	Floor Area	Peak Height
MSR MicroZoid Tent	100 x 35"	26"
MSR Zoid 1 Tent	113 x 41"	34"
REI Roadster UL Tent	82 x 32"	36"

Table 1.<sup>6</sup>

In terms of safety, the shelter must have enough structural stiffness and stability to withstand average wind speeds of 12.5 miles per hour.<sup>7</sup> Also, similar to tents and sleeping bags, it must have an acceptable degree of fireproofing.

Because of the transient nature of the shelter, its mode of disposal must be considered. Ideally, the materials to be used in its construction are biodegradable and nontoxic so that careless disposal will not be of much consequence for the environment.

### **Method of Approach**

<sup>6</sup> REI, available from <http://www.rei.com>.

<sup>7</sup> Jack Williams, "Chicago's 'Windy City' name," USA Today.com, 30 May 2002, available from <http://www.usatoday.com/weather/resources/askjack/archive-windy-city.htm>.



Many homeless people already construct makeshift shelters for themselves. Ones made of cardboard boxes are most commonly seen. A cardboard village thrived near a central transportation station in Tokyo until its homeless people were forcibly evicted in 1996.<sup>8</sup> Because of its affordability and widespread availability, cardboard is a good starting point for the design of a temporary shelter.

Numerous examples of cardboard construction can be found, and currently, it is especially of interest as a material for architecture. The Japanese architect Shigeru Ban has been experimenting with cardboard since 1986 and is well known for his use of cardboard tubes in a variety of building types such as pavilions, civic buildings, and temporary housing.<sup>9</sup> Buro Happold, an international engineering consultancy that has worked on several projects with Ban, has been researching the use of cardboard as a construction material for temporary structures. The cardboard school project in Essex, England was completed in 2001 with an estimated lifespan of twenty years and is made mostly of cardboard tubes and panels.<sup>10</sup> A recent design example is the Cardboard House by the Australian architects Col James and Stutchbury and Pape. Its intended use is temporary housing for any number of different situations.<sup>11</sup> Made mostly of cardboard panels, it requires only six hours for assembly by two people. Of course, the cardboard used in all these designs was not limited to the standard 3/16" corrugated type but

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<sup>8</sup> Tamae Ishiwatari, "Homelessness in Japan: Cardboard Village and the Shogun's Law," available from <http://www.share-international.org/archives/homelessness/hl-ticardboard.htm>.

<sup>9</sup> Buro Happold, "Constructing a prototype cardboard building: Westborough School, Literature Review," July 2001.

<sup>10</sup> Westborough School, Westcliff, available from <http://www.cardboardschool.co.uk>.

<sup>11</sup> Houses of the Future, available from [http://www.housesofthefuture.com.au/hof\\_houses04.html](http://www.housesofthefuture.com.au/hof_houses04.html).

involved different variations such as honeycomb, and was treated or layered with other chemicals or materials for waterproofing and fire protection. Although cardboard is typically seen as a low strength, light duty material, the applications seen in buildings prove it otherwise.

Cardboard is used in a range of smaller applications at the human scale, besides packaging and pizza boxes. A number of cardboard chair designs created by both famous designers and students alike exist. It is also used extensively as a material for storage systems. Cardboard boat racing originated in 1974 as part of a freshman design class at Southern Illinois University.<sup>12</sup> Now every summer, more than fifteen hundred people participate in this life-size boat-building event. Oil-free water sealants for the surfaces, and caulk or silicone for the edges are necessary for a boat to last the entire length of the course. From these examples, one can conclude that cardboard is a versatile material that can be easily adapted for different situations and is appropriate for use in the design of a one-person temporary shelter.

Cardboard, or paper in general, is made of cellulose fiber pulp that is highly compressed to form a felt.<sup>13</sup> In its final processed state, the water content of paper is six to eight percent. Cardboard is usually made of 100% recycled content and after use can be recycled, thus making it very environmentally friendly as a building material. It is a commonly observed fact that the strength of paper deteriorates as it absorbs greater

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<sup>12</sup> The Great Cardboard Boat Regatta, available from <http://www.gcbr.com>.

<sup>13</sup> Buro Happold, "Constructing a prototype cardboard building, Design Guide," September 2001.

amounts of water. Ways to improve its water resistance include introducing additives to the pulp mix during the manufacturing process, or applying an external coating to the surface, such as varnish, polyurethane [environment?], or Aquashield 2000. Like any wood based product, paper also burns. However, cardboard tends to char like wood, which prevents it from propagating the fire. Similar to improving water resistance, a varnish can be applied to the surface to prevent extensive surface spread of flames. Thermally, corrugated cardboard is similar to wool and provides a degree of insulation by trapping air between its fluted sheet and the plain sheets sandwiching it. The nominal properties of cardboard are defined in Table 2. For comparison, a solid 9” brick wall has a U value of 2.2 W/m<sup>2</sup>K, and a single glazed window has a U value of 5.0 W/m<sup>2</sup>K.<sup>14</sup>

<i>Properties of Cardboard</i>	
Thickness, N	3/16” = 0.00476 m
Thermal conductivity, λ [CIBSE A3-32]	0.047 (W/mK)
Thermal resistance, R = N (m) / λ (W/mK)	0.101 (m <sup>2</sup> K/W)
U Value = 1 / R	9.869 (W/m <sup>2</sup> K)

Table 2.<sup>15</sup>

Standard forty by thirty inch, 3/16” thick corrugated cardboard sheets cost ninety-nine cents each at local art supply stores. A range of larger sizes is available through paper supply catalogs such as [www.papermart.com](http://www.papermart.com), but freight delivery charges are only cost effective for mass quantities. (Ten sheets of forty-eight by ninety-six inch cardboard cost about thirty dollars but require over one hundred dollars in shipping.) Because of this

<sup>14</sup> Diydata.com, “Typical Values of building construction,” available from [http://www.diydata.com/information/u\\_values/u\\_values.htm](http://www.diydata.com/information/u_values/u_values.htm).

<sup>15</sup> Buro Happold, “Constructing a prototype cardboard building, Design Guide,” September 2001.

cost and availability restriction, the design process is carried out solely with readily obtainable forty by thirty inch, 3/16" thick corrugated cardboard.

## **Design Process**

Traditional Japanese origami was first looked at as a possible design strategy. The basic principle of origami is to turn one flat sheet of paper into a particular figure, usually three dimensional, using a series of folds. Similarly, a sheet of cardboard can be folded to form an enclosure. However, the complexity of most origami designs and their resulting forms cannot be directly translated to corrugated cardboard because of its thickness and structural rigidity. Also, origami figures are not designed to create occupiable space.

Paper folding was then looked at in broader terms, specifically, different methods of double pleating for creating form. In addition, deployable structures in the form of triangular, two-dimensional panels based on the Yoshimura pattern were studied. Because of their general patterns that can easily be manipulated, experimenting with these two methods of folding produced more plausible spatial results.

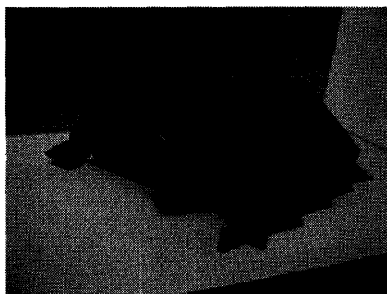
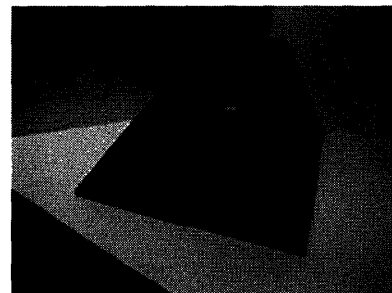


Plain white office paper and 1/32" thick chipboard were both used for experimenting with one-fifth scale models of possible design options. The first sketch model (see left) used double pleating to create a slightly arched roof surface with half of the folds utilized in the deployed state so that the structure could be

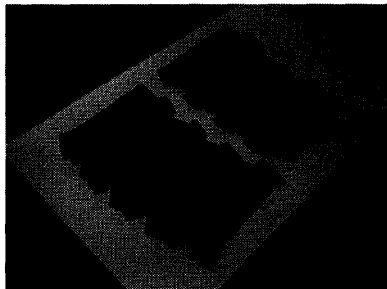
inserted into the base. A concern with this form was the interface between the different panels for the roof because there was no obvious way of overlapping or joining that would prevent leakage. Also, it was somewhat difficult to keep the roof in the desired shape without having some type of clamp to keep the folds together (see right). For the second design, the goal was to make it as simple a shape as possible. A triangular form is inherently more stable and also uses less material. Tabs were cut into one sheet to be inserted into the other.



Assemblies of two panels each were connected by cutting slits and sliding the assemblies into one another (see right). Although this was an easy and simple solution, the use of large uninterrupted panels made portability a problem. The next design kept the triangular shape but incorporated pleating as well for collapsibility (see below left). However, the pleating

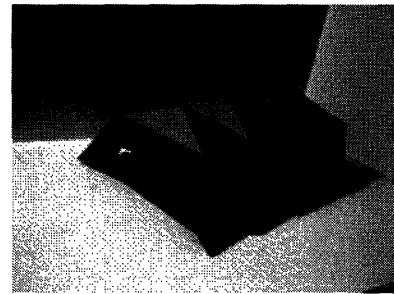


complicated the joining and overlapping of the panels at the apex. It was also difficult to determine how the side panels would interface with a ground plane surface.



To take a slightly different approach, variations of the Yoshimura pattern were then modeled in paper to get an idea of its possible applications (see next page right). The pattern was found to be easily collapsible and easy to overlap. A pattern using a  $120^\circ$  apex angle (see next)

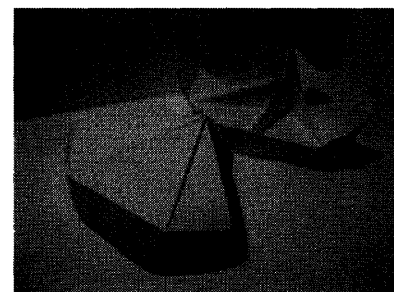
proved to have great potential, and was modeled in cardboard at full scale. The actual size of the structure and its interior space was underestimated after creating the one-fifth scale model. In full scale, the floor area measured only twenty-eight inches wide and forty inches long, and the apex height measured about fourteen inches. These dimensions would be desirable if the model was meant to be at half scale. From this result, it was seen that the forty by thirty inch sheets of cardboard would greatly limit the possibility of a simple, elegant solution to the problem. The model used less than four sheets of cardboard, and thus, if it were possible to obtain sheets double the size, the design would have great potential as a practical shelter.



Up to this point, every form explored was of the long, tubular type. To diversify and expand the possibilities, study models with a more centralized shape were created.

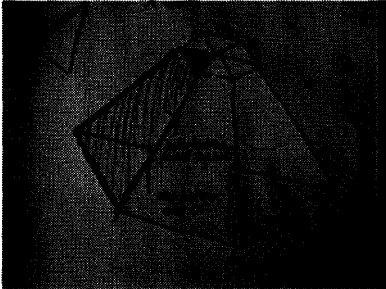


Taking inspiration from a pleated cup, a flat sheet of paper was folded to enclose space (see left). However,



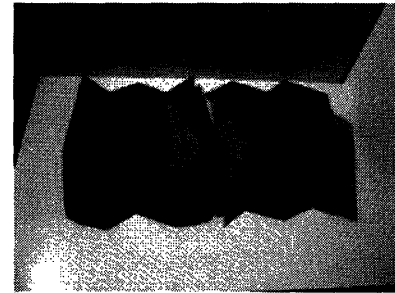
this proved difficult to translate into cardboard sheets. Double pleating (see above) was

looked at in a radial fashion as opposed to linear, but an effective way of joining the units at the center could not be determined. A panel system was also explored, but with the limiting factor of the cardboard sheet size, the practical maximum distance would only be about five feet for the floor area (see below).



After these fruitless attempts, the Yoshimura pattern was returned to, and the full-scale model was reevaluated. It was determined that a

larger pattern that used two sheets of cardboard to create an arch would suffice for size (see right). Using Velcro, the panels could be easily attached to one another and also to the ground panels. The final, full-scale shelter was

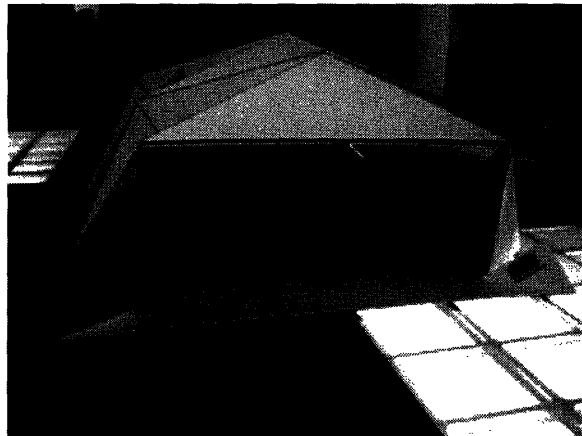


created in this manner (see right).

## Results

A one-person shelter was created using a Yoshimura pattern with a  $120^\circ$  apex angle. Every panel, except the two end ones, was a full forty by thirty inch sheet of cardboard. Each arch was made of two panels that overlapped at the center. Arches were strung together by

overlapping the panels. All of the overhead panels are identical; flipping the panels created two of the five arches so that there would be continuous overlap. The ground plane was made of four sheets of cardboard, two identical midsections and two identical end sections. The end section panels had flaps that could be flipped up to fully close the shelter (see right). All of the panels are connected with Velcro because of its affordability and reusability, and also for ease of assembly. Thirty-two inches of one inch thick Velcro, costing approximately seventy-five cents,<sup>16</sup> was used. A polyurethane finish by Minwax was applied to the surface for water-



resistance. The interior space is eighteen inches high, eighty inches long, and twenty-



eight inches wide. Completely collapsed, the shelter occupies about thirty by fourteen by eighteen inches of usable space (see left).

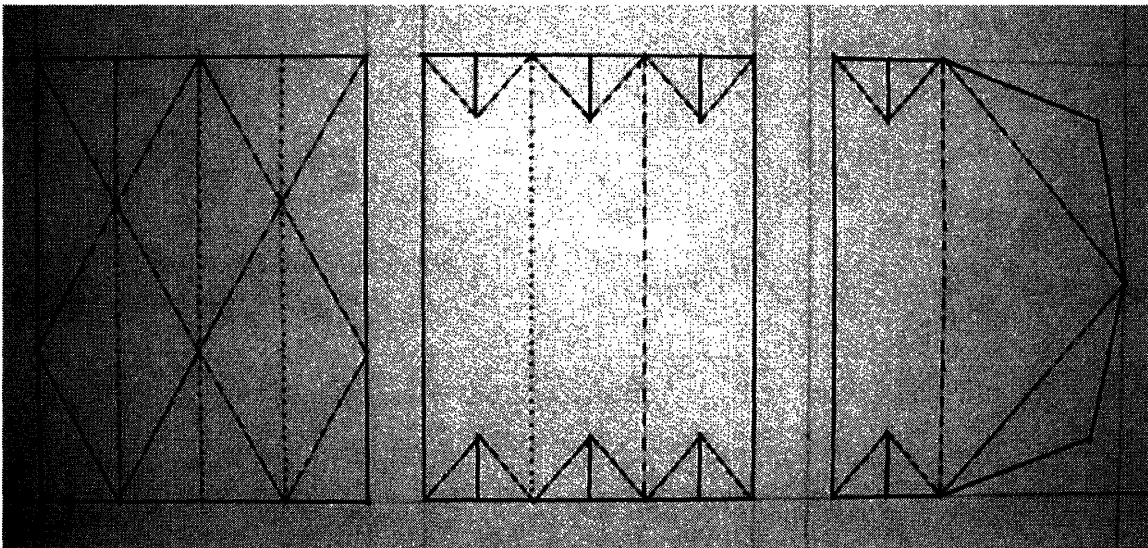
Although this design created an enclosed,

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<sup>16</sup> ULINE, Velcro Tape, available from [http://www.uline.com/Browse\\_Listing\\_5051.asp](http://www.uline.com/Browse_Listing_5051.asp).



water and wind resistant space that is suitable for the average person, many things would need to be improved in order for the shelter to be a practical, mass-produced product. Because of the small size of the cardboard sheets used, fourteen sheets total were needed to make the shelter. Having so many pieces required more overlapping and simply was not an efficient use of material. The number of pieces also makes the portability of the shelter doubtful, the cost unaffordable, and the assembly more difficult. Thus, the prototype constructed of forty by thirty sheets of cardboard is not the best, or final solution.



Panel Diagrams.

## Conclusions

The size of the cardboard used in the design process was a much larger influence on the final result than originally thought. If the same overall form of the prototype was constructed of forty-eight by ninety-six inch sheets, the total sheet area could be cut by at least half because there would be much less overlap required. Larger sheets would also have required fewer connections, making it easier to construct and also more water and

wind resistant. Another limiting factor was the method used in folding the cardboard. Standard cardboard boxes are simply creased and thus, flanges can fold in either direction. Because the tools were not available to crease the cardboard, scoring was used and that restricted folding to one direction. More flexible hinges would have allowed more possibilities in creating connections between the panels; Velcro would likely not have been necessary. Scoring also opened up the surface of the cardboard, which created more holes and increased the probability of leakage.

Despite these drawbacks, a lot was learned in how to utilize folding as a method of creating structure. From the prototype created, folding was demonstrated to be better than simply assembling flat sheets because it created a more sturdy and collapsible structure. Using the folding method with large sheets of cardboard as a material, a simple solution to the problem of temporary shelter for the homeless in harsh weather is feasible.