The Optimal Humanitarian Aid Shelter

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An exercise in applying an optimization function to an architectural and human problem in disaster relief

Disasters, both man-made and natural, put a strain on local environments. The best way to handle such a situation is to be prepared for it. A good example of not being prepared for a situation would have to be with Hurricane Katrina and more recently the earthquake in Haiti. The unfortunate thing is that planning for disasters involves a learning curve. It is a very reactive process of learning from our mistakes. To decrease the number of mistakes that are made careful thought and planning are crucial steps. This research paper has sought out the optimal shelter for humanitarian aid purposes. Housing people in a disaster provides some of the security that the victims had in their homes. It is important that this is done quickly. Several case studies were done on a variety of shelters designed for humanitarian aid relief. This study asks the question: what is the best tent?

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This design research topic is about the need for humanitarian aid when a man-made or natural disaster occurs. While there are many things that need to occur after a disaster, one of the first things that needs to occur is to build shelter for those who have lost, quite possibly, everything. Shelter can bring security and at least a little peace of mind to those who have been displaced due to a disaster. How can architecture provide spaces to house people? Finding the most effective shelter to be used for sheltering people in a hurry in any environment would be crucial to relief efforts. This research topic can be boiled down to the simple question, 'what is the best tent?'

However it is not such a simple question. Instead of looking at several examples of relief shelters, making a subjective judgment, and saying which tent is best there has to be a way to defend why an example is the best. Personal judgment can be used and actually is used a lot in the profession of architecture. The public counts on architects to make the best or optimal decision many times every day, literally counting on architects with their lives, to make critical judgments about structure and materials. Sometimes just saying what the best decision is might not be the best answer, even if it is based upon purely what an architect thinks. If architects learned how to do optimization functions, they would have another tool that could be used to show why their decision is the best option. This is not to say that all decisions should be made in this manner. For example there are some things, such as aesthetics, that cannot be quantified. However, this research problem does not focus on the questions of aesthetics or beauty. Rather it focuses on a fairly pragmatic problem: sheltering people in the most basic, simplest, and effective way. It is ultimately more important to make sure that people get their basic needs taken care of after a disaster rather than their desire for a beautiful dwelling. At the point after a disaster the focus should be on taking care of the victims, which is why an optimization function is probably the best way to work on a problem such as this. It seeks to find the best answer objectively.

Optimization functions, a form of applied mathematics, are used every day in business, law, and science, but they are not used too often in architecture. An optimization function includes variables that can be measured, and constraints that limit them. From the set of variables and constraints the function arrives at the best, or optimal, option. Functions are either a maximization or a minimization. It depends on what it is that is being measured. For example in a business sense they would show how to make the most profit. The challenge, after first learning how to use optimization functions, is figuring out what will be used for variables and then finding a way to quantify them. After conducting the case studies, gathering all the information for the variables, setting up the constraints, and creating the function the easy part should be solving the function and arriving at the conclusion. No matter if it is what had been originally hypothesized.

The function that was developed for this research project was a simple linear maximization. In a maximization function it is the highest quantity that is the optimal outcome. The sum of the constraints makes the function linear. There are many more complex options, but this is what was decided to be used. While there is multiplication and division in a few of the variables, there is only simple addition used to find the sum of the constraints and therefore the optimal conclusion.

Shelters:

The shelters that were researched for the case studies were found through searches on the Internet, and the book by Architecture for Humanity, *Design Like You Give a Damn*. The case studies are two models of Pacific Domes, the 16' and 24' model; Concrete Canvas Shelters, model CCS 25; the simplest of the Hexayurts; Tridomes, which is an adaptation of the Hexayurt; and a ten foot diameter Superadobe structure, developed by Cal-Earth using materials of war. The reason why there are two examples of Pacific Domes and Hexayurts used because each of the examples are different enough from each other to warrant further study.

Pacific Domes:

Pacific Domes use the shape of the dome to create a stable and efficient way to envelop space. They are relatively quick to set up requiring only a few man hours for each unit. Two different sizes of domes were chosen to be studied. Those examples are the 16' and 24' models. They both use the same process to setup. However, the 16' model only takes two hours to setup with a crew of two workers while the 24' example takes three hours with the same size crew. The difference is two total work hours. The main difference is made up in that the larger 24' model houses eleven people, and the 16' model houses seven.

Concrete Canvas:

Concrete Canvas is a corporation in the United Kingdom that makes the eponymous concrete canvas, which is a material that is impregnated with concrete. These shelters are a technology that uses the Concrete Canvas surrounding an air tight bladder, soaked with water and then inflated to create space while the concrete is curing. Once it hardens the bladder can then be punctured and be used, this takes between 12-24 hours. The time to usability is not its only weak point. A CCS weighs about 4000lbs, not something that can be moved easily by a small team of workers. Some other drawbacks are that it requires electricity to power the pump used to inflate the bladder. It also takes a lot of water to hydrate the cement so that it can cure. The benefits are that there is only a short setup time. It takes two people about an hour to inflate and wet down before moving on to the next unit. Because of the short setup time a lot of units can be setup in the short critical time. The space inside can be sterilized to house medical functions because of the sealed interior. Concrete Canvas Shelters are structural enough to be 'bermed'. Berming means that they can basically be buried with earth. Should Concrete Canvas Shelters be setup in an area where there is armed conflict the berming would help with protection from shrapnel and small arms fire. There also is some thermal protection gained by berming.

Hexayurt:

Hexayurts are structures that are made out of any standardized building material that is 4' by 8'. The method of building these produces structures with zero waste involved. They were developed by Vinay Gupta, who looked to Gandhi and Buckminster Fuller for inspiration. Given twelve sheets of 4' x 8' plywood structure can be built that houses four people according to the Sphere Project. The process used in building these structures is simple. Six pieces of 4' x 8' plywood are cut in half diagonally. Each piece is then fastened together to make a triangle, each of these triangles are then joined together to create a hexagonal pyramid which serves as the roof of the structure. The walls are full sheets of plywood laid on their long side which the roof is set on top of and fastened together. A door and windows can be cut out of the walls.

The example used for the optimization is made out of plywood. That does not mean that the only material that Hexayurts can be made out of is plywood. Any material that is produced in a standard 4' x 8' shape can be used for construction of these structures. Since the example I am using is built out of plywood it would be susceptible to fire. It also would not have much in the way of thermal protection. They are easily built and setup by only a couple people and can be taken down and used somewhere else after they have been built. A Hexayurt can be built out of readily available materials cheaply, because of the use of standardized building materials. They do not produce any waste from the building process. The Hexayurt also does not require any specialized pieces, or much skill to setup. This structure uses the entire sheet of plywood to make the structure work. The piece that is cut out for a door is used as the door. With zero waste it is also a cost effective means of building humanitarian shelters.

Tridome:

Expanding upon Gupta's ideas Edmund Harriss, a mathematician at the University of Arizona, took the simple roof a combined them into different variations that allowed for bigger structures. He also expanded upon Fuller's Geodesic dome ideas and came up with Nearodesics. Nearodesics creates structures that are much like the spherical trigonometry of Geodesic domes, but uses only standard 4' x 8' building materials without creating waste (Gupta, 2010). Geodesic domes take a certain amount of skill to construct and also produce a significant amount of waste (Harriss). The Tridome uses three of the Hexayurt roof structures mentioned earlier and leans them against each other. There are only small square holes that are left behind to be filled in using half sheets of plywood (Harriss). A half sheet of plywood, or other building material, can be tolerated in a disaster situation. Leaning the roofs together Harriss has created a larger structure using the same principles as Gupta.

Superadobe:

Superadobe is a building system that uses materials used in fighting wars (sand bags, and barbed wire) to create shelter for people who are in crisis. It was developed by Nadir Kalili, an Iranian-American architect. In a series of emails from Ian Lodge with Cal-Earth it was found that Superadobe can take from two to six hours to setup, depending on whether the sandbags are already filled up. If the sandbags that make up the Superadobe structure are already filled it will take a crew of seven people two hours to setup, if they are not it will take the same crew an additional four hours to fill the bags that are used. Assuming that the disaster and recovery that will be simulated with this optimization will be under ideal conditions with everything at the ready the sandbags will be filled up previously. This means that it takes a total of fourteen man hours to construct an emergency Superadobe shelter that is then immediately usable and can shelter about four people. The size of the Superadobe shelter can vary greatly. The 10' diameter model was chosen for it being more structurally sound.

The only cost associated with Superadobe could be with purchasing the bags from Cal-Earth. This does not have to happen if there are sandbags already in site, but this cannot be counted on. Superadobe was developed as a product of materials of war. Sandbags and barbed wire are materials that are readily found in any war torn country, but since this situation does not count on that the bags will be purchased as previously mentioned.

Resources:

The main resource that was used is known as the Sphere handbook, which is published by the Sphere Project. It was started in 1997 by humanitarian aid groups such as the Red Cross and the Red Crescent to set up standards for which to respond to a disaster or crisis (About Sphere, 2010). The means through which the Sphere Project has done this is by the writing and publishing *Humanitarian Charter and Minimum Standards in Disaster Response*, which is better known as the Sphere Handbook. The Sphere Project is ultimately three things: the handbook mentioned above which is described as 'a broad process of collaboration and an expression of commitment to quality and accountability.' (Humanitarian Charter and Minimum Standards in Disaster Response, 2004) The Handbook and principles therein are meant to be used as a response to a disaster. It is a valuable resource that has had over 400 organizations in 80 countries collectively contribute valuable data from the field to it. It is by no means a disaster how to book. The individual procedures and methods of reacting to a disaster are up to the individual agency that chooses to adopt the standards that the *Handbook* presents.

Constraints:

There were a number of constraints that were developed for this optimization function. The constraints are the number of units that can be setup in forty-eight hours, the occupancy per unit, the usability of the cases, the number of people that each case can shelter after the critical first forty-eight hours, whether or not the units can be reused, and how many units can be purchased for one hundred thousand dollars. The variables involved are the number of people and time that it takes to setup a unit, the floor area per unit, whether a unit is reusable, and the individual cost per unit.

Units setup in 48 hours

Each case that I have found gives a setup time with a certain number of people that are needed to set it up. The number of people multiplied by the hours of setup gives us a total number of working hours for setup. According to FEMA (find source), the first 48 hours in a crisis is the most important. Since most of the cases require two people to setup and buddy pairs are typically the smallest unit the relief workers will go into the field, nobody goes anywhere without a buddy. Also working in relief, workers follow a work/rest plan and for this part the workers can only work 16 hours per day, followed by 8 hours off. This is due to the researcher's personal experience with search and extraction training. The question is how many of each case can the fewest number of relief workers setup following their work/rest cycle in 48 hours. With two workers following this work/rest plan they can work a total of 64 man hours in 48 hours. 64 working hours will be used as the total number of hours that can be used to setup any number of units per case. This will derive the maximum amount of units that can be setup, and hopefully housing the most people.

Occupancy

The size of each unit will determine how many people can be sheltered in each case. There are guidelines that are set out by the Sphere Project that say that each person is allowed 3.5 square meters, about 40 square feet, to live in during disaster recovery operations. After figuring out the floor area of each case in square meters and dividing by 3.5 a number occupants will achieved. One trouble with this will be that some units result in a decimal after the whole number. This will have to be rounded off and only whole numbers will be used. The extra space would be unusable by an extra person to live in, and the remainder cannot be carried over to another unit.

Units ready after 48 hours

The second variable is dependent on the first one. Time to usability is important if you cannot use it for the first 24 hours, such as with the case example of Concrete Canvas Shelters. The cement takes time to cure before the bladder inside of it that was used to inflate it can be punctured and the space used. This is the only example that takes more time than just set up to be used. This does not make it ideal with this variable, but will be interesting to see how the other ones come into play.

People sheltered in 48 hours

There is another question that is begged because of the materials used in one example. The Concrete Canvas Shelters cannot immediately house people in a crisis because the concrete must cure first. So it asks the question of the immediacy of use.

Reusability of units

A unit being reusable is important as well. Should there be another disaster the units would be able to shelter another group of people with the same initial capital investment. If a shelter can be dismantled and setup in another location for another disaster or different use it would be beneficial. It would save on cost.

Shelters for $100,000

The cost of a unit is going to be a critical constraint. Shelters still have to be bought and paid for. The most cost effective choice may win out, but the optimization will have to be looked at in order to determine which is best. It might not be the cheapest one. The initial trouble with this constraint is that cost itself is a minimization. The cheapest one would be the best is cost were the only constraint. However, this is not the case. To turn it into maximization there had to be a number to divide the cost by a arbitrary monetary amount to get a maximum number of units. There are no guidelines on FEMA about how much this should cost, only about eligible expenses. Because there were no guidelines a dollar amount was set to judge each case. One hundred thousand dollars was a figure that gave close enough numbers to give a fair function.

There are other variables that could have been used such as Weight, Fire Resistance, and Variety of Uses. More variables would have further developed the function. Also another challenge would be with how to measure these other variables. Weight does not matter if you have the equipment to move a unit, but you have to have the equipment. How can fire resistances be compared? Hours it takes to burn? Concrete does not burn so the CCS25 would be the ideal one for that constraint. There are variety of spaces that need to created and facilitated during humanitarian aid, but this research problem focused on shelter. There is a case that I am studying that can be sterilized making it ideal for medical facilities. Also the environmental impact of each of these shelters cold be used in the function, the question is just how, and was not developed within the time given for the research project. These are all different example of how this function could be developed further. This is not the end of this, but the beginning.

Case	workers	setup time (hrs)	total workhours	units setup	area (m^2)	occupancy
16' Pacific Dome	2	2	4	15	18	5
24' Pacific Dome	2	3	6	9	40	11
CCS 25	2	1	2	32	25	7
Superadobe	7	2	14	4	7.3	2
Hexayurt	3	2	6	9	15	4

usability	units ready after 48 hours	people shelter in 48 hrs	reusability factor	reusable units
immediat	15	75	1	15
immediat	9	99	1	9
24 hours	16	112	0	0
immediat	4	8	0	0
immediat	9	36	1	9

cost	cost to shelter a person	shelters for $100,000	people sheltered	optimization
6900	1380	14	70	139
13000	1181.82	7	77	144
18913	2701.86	5	35	172
550	275	181	362	199
100	25	1000	4000	1067

Conclusion:

According to the optimization the most effective humanitarian aid shelter is the Hexayurt. It is a simple design that can house an average amount of people with little setup time and with cheap materials. Cost is the more important constraint for the Hexayurt's effectiveness. Especially when it came to how many can be purchased for one hundred thousand dollars. It is cost effective and made out if materials that are premade and purchased.

Another benefit of the Hexayurt is that it is public domain. Anyone can use these ideas and build one, because it is not the intellectual property of anyone. Also, because it is not owned by anyone this allows for people to innovate and adapt the idea. Visiting the Hexayurt website one can see how the original idea has been adapted. There are many different ideas on the website.

The benefit of this project and this research is that someone may actually be able to use the data that has been compiled and analyzed. This is not the case with most design studios. Most, of course, focus on design and theory. Both of which are used in design, however those are not the only things used. A research was beneficial in that it allowed deeper exploration into a subject of importance to the researcher. Humanitarian aid is also a very real issue in today's society. This would be a positive addition to any curriculum of architecture design.

Nick Corniea is a graduate architecture student at North Dakota State University. He served in the Minnesota Army National Guard for 9 years as a carpentry/masonry specialist as well as a member of the CERF team for FEMA District 5. Humanitarian Aid and Relief, and Recovery Operations are a focus of his. He lives in Fargo, ND.

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