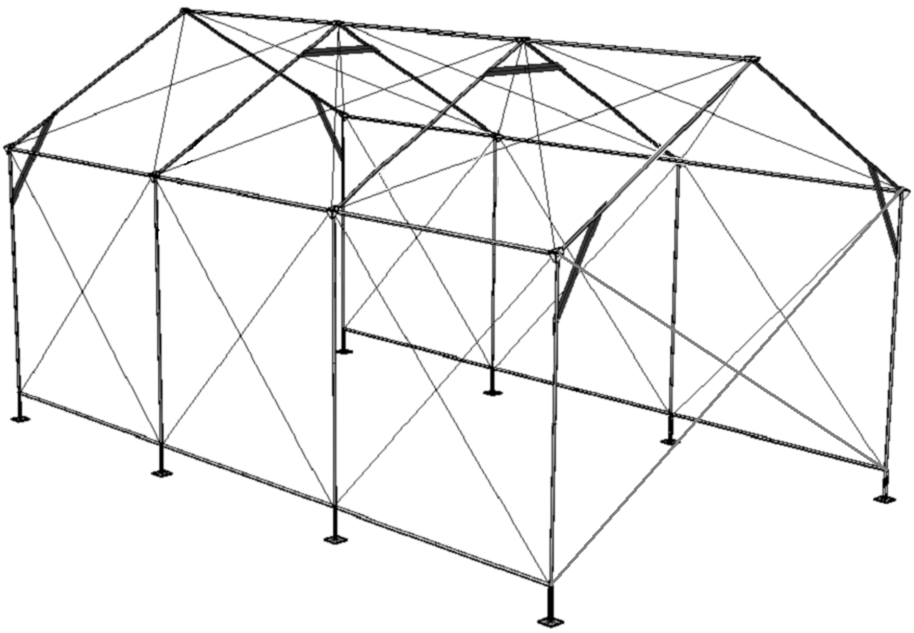

Development of a Light Weight Structure for Emergency Housing of Refugees

Master Thesis in Product Development

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Department of Product and Production Development
Division of Product Development
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2011

MASTER'S THESIS 2011

Development of a Light Weight Structure for Emergency Housing of Refugees

Master of Science thesis in the Master's programme Product Development

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Development of a Light Weight Structure for Emergency Housing of Refugees

Evaluations and proposals for improving the metallic structure

Master Thesis runs with The Emergency Housing Project

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Cover:
Proposed design configuration of metallic structure for the Emergency Housing Project
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Master of Science Thesis in the Master Program of Product Development
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ABSTRACT

In the present work, a description of a light weight structure frame for housing during emergency relief is described. It is explained how in different disaster situations around the world the demand for a durable yet fast solution is increasing and how this frame addresses those issues.

The methodology and practices for evaluating and developing the frame and each individual part of it are also explained. From an initial market scanning to the input of research papers and experts experience, several sources were used as reference. This real input transformed into tangible requirements was needed to achieve a product that makes sense in a human and economical way.

The requirements evolved while different stages of the development were considered. At the end, besides the requirements stated by the non-governmental organizations, requirements of transport, manufacturing, expansion and economical were included to ensure the success of the tent as a product.

The final solution, based on high strength steel, was optimized using different virtual tools. Statistical tools like design of experiments were used to find the most efficient configuration of reinforcements and with finite element analysis the individual parts were tested to ensure its proper behavior and security in normal weather conditions.

The final user was kept in mind throughout all the process; however a strong emphasis to make economic sense to all stakeholders involved as a determinant factor in evaluating different ideas. Over all, the guiding idea was to create a frame that had the property to be used as an immediate response solution but that will be able to evolve with its population into a durable solution with the use of local material and labor skills.

Keywords: Emergency housing, steel frame, product development, disaster relief

Acronyms

NGO	Non Governmental Organization
UNHCR	United Nations High Commissioner for Refugees
IFRC	International Federation of the Red Crescent and Red Cross
IDP	Internally Displaced Person
ERT	Emergency Response Team
DSM	Design Structure Matrix
OCHA	Office for the Coordination for Humanitarian Affairs (UN)
MSF	Médecins Sans Frontières (Doctors without borders)
ICRC	International Committee of the Red Cross
UNWRA	United Nations Relief and Works Agency
UNICEF	United Nations Children's Fund
UN	United Nations

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Agustin Vargas Nasser

Gothenburg, July 2011

1.Introduction

This work is written to be my master thesis for the master program of Product Development. It aims to demonstrate the knowledge acquired through the program in a practical specialized task. It is written accordingly to the Master thesis rules at Chalmers University of Technology.

The study was performed on shelters for humanitarian assistance in emergency relief. All the work that the thesis covers is based on the metallic structure of such shelter which in the following will be called as tent, based on its use and similar products.

It is explained how the tent is being used by the humanitarian organizations. This is with the purpose of understanding how the stakeholders work and how the design is considering them. The lives of the people living in the tents, either refugees or internally displaced people, are only explained to motivate some of the design features and requirements.

The thesis work is based on the collaboration with a real product denominated “Light weight steel structure” developed by Formens Hus. This project had been running for some time before my incorporation to it. Formens Hus works in association with Triple Steelix and funds from the IKEA foundation to be introduced by the UNHCR and the IFRC.

My participation on the project is as follows: Evaluate the actual solution and present well motivated improvements to the actual design. Design new parts and modifications to the actual parts. Collaborate in the assessment of ideas and evaluation of them. Review the requirements stated by organizations around the world and verify their compliance by the final design. The work is divided in four parts: market analysis, establishing requirements, solution development and final evaluation. This division is to give a format that goes accordingly to the focus of the program of MSc. Product Development.

1.1Why Shelters

In the event of a natural disaster or conflict thousands of temporary shelters are needed within a very short time span. Due to the nature of these situations the need for shelter far exceeds the logistic capacity; therefore the “iconic” heavy and bulky refugee tent is abandoned in favor of simple, but very effective, plastic sheeting. At the same time, the need for an intermediate and transitional solution from the first onset of a disaster to a permanent solution is achieved is greater than ever. (Kanter & Karlsson, 2010)

Shelter is important because it protects us from the elements, provides us with a basic sense of security, and a place for our families to interact. But it is also linked to many other aspects of what we consider “normal life”: privacy, independence, dignity, safety. Shelter is fundamental to the enjoyment of many human rights. (UNHCR Canada, 2007)

The world has many problems. According to the United Nations Refugee Agency, over 30 million people live in a refugee status without counting the 4.7 million in Pakistan. (United Nations Agency for Refugees, 2009) These refugees live in several different conditions of settlement and status, from being close to resettlement to simple tarpaulins in poor conditions.

In this context, a shelter is more than just the material it is made of. Its value relies on the difference it represents to in its habitants life. A shelter is critical for survival but it also provides security and personal safety, protection from the climate and enhanced resistance to I will health and disease. It is also important for human dignity and to sustain family and community life as far as possible in difficult circumstances. (The Sphere Project, 2004)

After a disaster, the immediate response of governments and international organizations is critical. The effectiveness of their actions is relying both in the measures taken and the equipment and support given. Here is where the design quality of the items brought to the people in despair takes its role. A wrongly chosen product could simply bring temporal improvement or even affect the well being of the most vulnerable. A shelter must also be seen as a product. In order to keep it efficient and in constant upgrade the normal variables a product has like cost, transportation, manufacturing, storing, etc. shall be controlled as in any other product.

There is a high relevance in the effort in engineering development on shelters if seen as a product. Several different suppliers and stakeholders must be considered plus through the years many standards and guidelines have been established by different organizations around the world. The market they represent is considerably big and the competition is increasing. Only a good product, well founded on the most critical requirements could take the lead.

During this thesis I will show my participation in the development of a new shelter that at the same time of fulfilling all the requirements and standards it also incorporates innovative solutions to some known issues and allows for a good business case, without dismissing the most important thing: The families they will host.

1.2 Involved Organizations

This project was done with the support of several organizations. In this part a little explanation of each one of them is given and their role and involvement in the project.

The Emergency Housing Project is run by Formens Hus with funding from the IKEA Foundation with collaboration from UNHCR and in partnership with Triple Steelix. I have been running my thesis project together with Formens Hus and Triple Steelix, tutored by Dennis Kanter and Bengt Löfgren from respective organizations.

About Formens Hus Foundation

Stiftelsen Formens Hus i Hällefors is a non-profit organization in Sweden devoted to sustainable development through design. The Formens Hus foundation runs educational programs in design and carries out development project within the field of sustainable design. (Formens Hus Foundation, 2009)

About the Emergency Housing Project

The Emergency Housing Project mission is to create a better living for the millions of people displaced by natural disasters and conflicts. In joint collaboration with innovative companies and organizations we develop flat-packed homes which save lives and contribute to a sustainable development to affected societies. With focus on the end user needs and a rational design process we create emergency housing solutions to deliver short and long term value. (Formens Hus Foundation, 2009)

About Triple Steelix

"Triple Steelix is a place where the small and medium-sized businesses can get the extra skills that are often needed in order to develop successful products and services. It can just as easily apply to how to weld new advanced steel as how to identify and process a new market in Sweden or abroad. " (Samuelsson, 2009)

Figure 1 Refugee tent in Palestine http://electronicintifada.net

1.3 Objective as Stated by Formens Hus

In close collaboration with industry, the objective is developing a state of the art steel frame solution that allows rescue agencies to save more lives, and the displaced people to live a better life during and beyond the phase of an emergency.

Project Aim

To bring a light weight steel frame intended for humanitarian agencies to use in the immediate onset of an emergency to production. The frame shall be able to carry a wide range of cover materials, from the first emergency tarpaulin to intermediate solutions like fly-sheets or hard panels to long term solutions made of local or standard building materials.

Project Scope

The project scope is limited to the construction of the frame only; any development of a cover does not lie within the scope of this project. Within the scope lies to define proper constraints and technical specification relevant for the design as well as production methods, surface treatments etc.

Project goals are a final prototype and a set of technical drawings to be used as a ground work for production.

As a result the project output will be:

- Design specification and constraints (weight, volume, wind load, snow load etc)
- Drawings of detail solutions (ground anchors, bracing, joints etc)
- Prototypes of the above

External project input from Formens Hus and Partners:

- Basic design brief
- Basic design specifications (Shelter Centre Standards)
- Benchmark product (UNHCR/IFRC Family tent)
- Basic layout of tent frame
- Preliminary joint and pipe prototype
- Humanitarian feedback (UNHCR and others through Formens Hus)
- Production Knowledge (Triple Steelix, SSAB and IKEA of Sweden)
- Knowledge of material (Triple Steelix, SSAB, IKEA of Sweden)
- Vast network of competence, tutoring and study visits
- Financial input in terms of prototypes
- Financial input, travelling costs etc (cost limit to be defined)

1.4 Delimitations

The project does not cover the design or development of the panels or fabric cover for the tent. However it does consider their existence in the development of the frame and the parts that constitute them.

The approach of the thesis is mainly from the engineering design point of view so humanitarian and social aspects are only researched with the purpose of tent design. It is not the purpose of this thesis to present political solutions for the humanitarian response organizations, neither the economic or logistics issues that cause the demand for shelters.

It is also only focused in the tent as an individual, it does not relate to the camp as a composition of tents and therefore it will not deal with aspects of tent organization and logistics.

The thesis project lasted for little over 20 weeks, from January till May of 2011 and it used financial resources for travelling expenses and prototype manufacturing.

1.5 Layout of the Report

The report is divided between two main sections. In the first section, general concepts of Product development theory and methods are explained. These concepts include QFD, Development funnel, Market analysis methods, etc.

In the second section, the main project is described using as a base most of the concepts explained in the first section, starting with a market analysis that will be focused in understanding the environment and the users of the product. This information was taken from other thesis projects, news archives and official reports from the major organizations in humanitarian assistance around the globe.

The following part, Requirements, will evaluate the requirements the lives of the users explained in the previous section will have. It will also examine the official publications of the main contributors in the area to evaluate how can their requirements can be adapted to our project. Also in this part, a benchmark of different solutions that are available on the market will be performed.

At the end, solution development is where the engineering and design takes place. Every step of the modifications and conception of each part will be explained here. It shows in a short way, the process of the design of the tent and how requirements and stakeholders were considered in it.

To conclude, an overall evaluation of the product will be conducted. It will try to encompass the entire previous steps and show the final result of the development process.

1 Section 1, Product Development Theory Background

In this section, product development theory is explained to give the reader a background on some of the main concepts studied during the masters program and that are very important in understanding the following work

2.1 Product development process

The aim of any development process is to bring an idea into a successful product in the market. Several ideas must be taken into account, evaluated, refined and only a few will be good enough for going into the market where even less will be a success. There are several different approaches and theories around product development. Depending on some factors like the market, type of product or company, they use different techniques and approaches to reduce the resources, risk and time needed in the process.

In the next pages, a few of those ideas and methods will be explained to give the reader a background on the development process. Not all of the techniques showed have been used directly during the development of the emergency housing however, they are important in the existing literature.

2.1.1 The Development Funnel

A basic representation of the process a product takes from conception to launch is represented by the so called development funnel. (Wheelwright & Clark, 1992) In its simplest form it provides the basis for representing in a graphical way the process that filters different ideas into a single output.

The development funnel works only to represent a theoretical concept. Every company would have a different shape and type of input/output of their model; however two main models can be drafted. The first one, shown in Figure 2 (Wheelwright & Clark, 1992), driven by the research of a company, where many ideas are trialed and carried along the development process and where some might make it to the market. This is, generally speaking, the model large firms with extensive resources follow. It may have screens throughout the funnel, similar to the gates in the stage-gate system that filter out those projects or ideas that do not comply to the firms strategies.

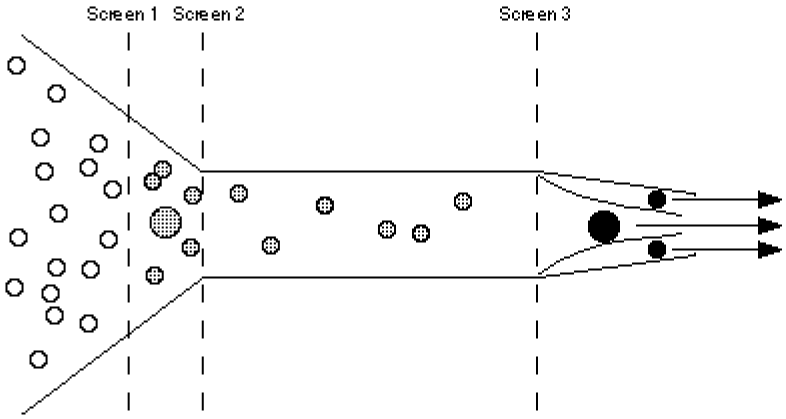


Figure 2, Model I Development Funnel

The second model, displayed in Figure 3 (Wheelwright & Clark, 1992), is more adequate to smaller firms which cannot afford to research in so many areas at the same time. This model is called “a few big bets” and is based on designating a proportionally large amount of resources to a limited amount of projects early in the development process. It is certainly a high risk approach but quite useful for companies where the market and the product are well known and there are not enough resources for evaluating several ideas at the same time.

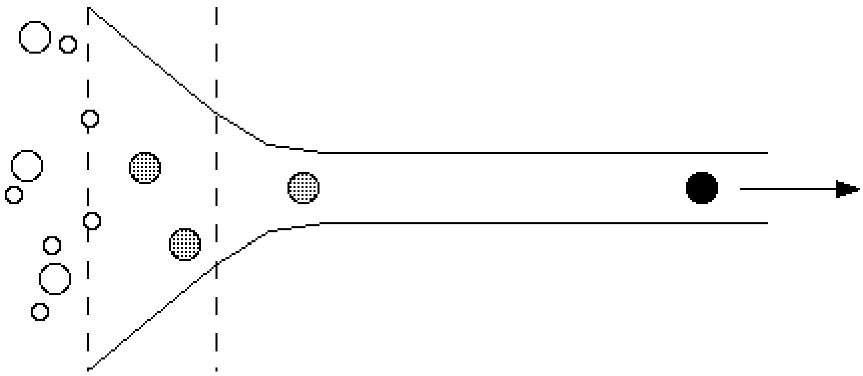


Figure 3 Model II Development Funnel

2.1.2 The Stage-Gate System

There are several steps in the development process of a product. The stage-gate (Cooper R. G., 2009) system is a conceptual road map for moving the product from idea to launch. It divides the process into several stages, each one guarded by a gate. Usually there are six stages in a normal project, considering that the development strategy of the company has been well thought-out before the start of any project. During those, information is gathered and tasks are undertaken by the project team. Stages serve as quality control and go/kill will check points.

In its pure conceptual form, the stages are all cross-functional, avoiding having an outdated development organization in which the R&D stage follows the marketing stage and is followed by the production stage. In the stage-gate model, all stages include steps to be followed by all functional areas of the development process. Activities run in parallel by people from different functional areas.

It is not a new idea that through the evolution on any development project, costs are increasing, new information is generated, the space for new modifications is diminishing and the total risk of the project is escalating. The stages are controlled amounts of development which get restricted by ordered gates in which a project can get stopped before the risk is too big or the costs are too expensive for the firm to take. It also helps plan the resources and the time a project might take.

It is not hard to see how the stage-gate system is a mature concrete form of the development funnel idea explained in the previous chapter. Several ideas go into the funnel and through the pass of some gates, some of them get disposed and some are invested on to become launched products. The typical stages are as represented in Figure 4

The success of the stage gate system is based on three things. First of all there should be a global strategy on which all products will be directed to. The second factor is that gates must be respected and enforced by everyone in the company and the third factor is that gates are established on advance and are based on defined outputs.

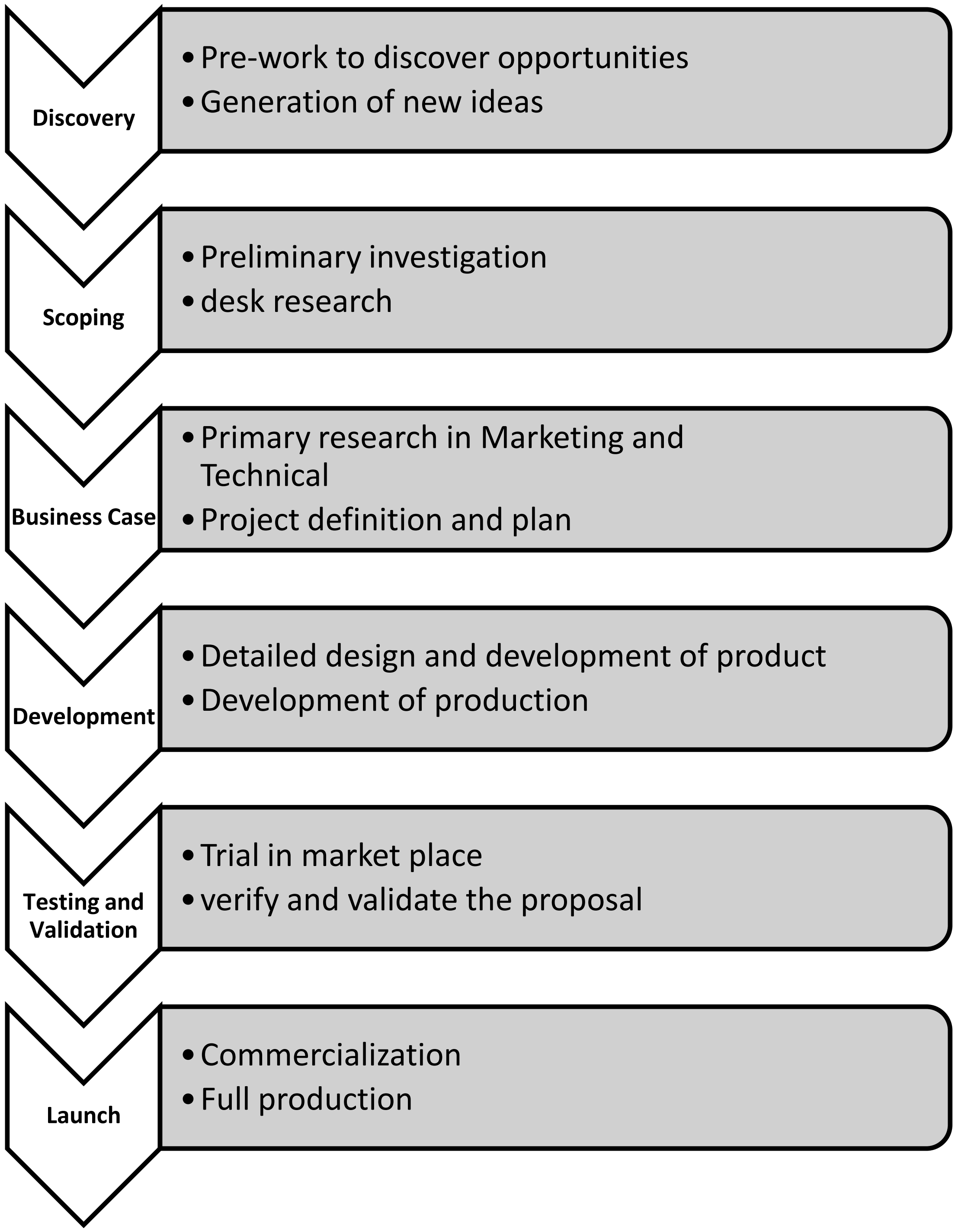


Figure 4 Stage-Gate development process

2.2 Methods and Tools

To organize different parts of the design process and to evaluate them in an orderly way, several different methodologies and tools have been designed. Some of them try to evaluate abstract concepts in a quantitative way while others are more pragmatic and use complex statistical functions.

In the next section, a few methods for evaluating designs and parameters are presented. The most common ones are explained and the relationship between them. It will be clear to the reader that common and simple concepts like benchmarking and SWOT analysis provide the basis for more complex tools like quality function deployment or robust design.

It should be considered that several methods should be used to take well based decisions and it should also be acknowledged that information from one method can greatly increase the performance of a second method. In the next pages such relationship is presented between the marketing methods and the engineering design ones.

The methods chosen to present in this section respond to two main criteria: either they were clearly used during the project or their importance in the development process is such that must be mentioned.

2.2.1 Market Analysis

In this section, different tools for market analysis are explained. Considering that this project had been running for some time before the thesis work was done and that market analysis is usually one of the first steps in development, the strategies that are presented in the following pages are more focused to review that the correct layout of requirements and methods is present.

Basic but important concepts like the Kano model and the SWOT model are presented to give the reader a background to understand the development section. It is also important to mention that these basic models are the base of more complex techniques later explained like Quality Function Deployment and Robust Design.

SWOT analysis

A SWOT analysis (strengths, weaknesses, opportunities and threats) (Hill & Westbrook, 1997) is a commonly used tool for laying out the map in the development strategy of a project. It explains the conditions a project might have and based on them, evaluates if it has an attainable goal. In combination with other methods it can greatly improve the development of requirements and design processes of a product. The reason for using these four elements in SWOT is to evaluate the internal and external advantages and disadvantages a project might face in the development stage. An internal advantage would be the strengths and an external disadvantage would be considered a threat.

The results of a SWOT analysis are usually expressed in a table with a layout similar to Figure 5 where on the lateral side is the internal or external factor and in the horizontal side the advantages or disadvantages.

	Advantages	Disadvantages
Internal	Strength	Weakness
External	Opportunity	Threat

Figure 5 SWOT layout

Although this analysis brings no conclusions, it helps transmit and understand the situation a product will have during its life cycle and therefore help prevent problems that might appear later in the development.

The Kano model

The Kano model is a well spread theoretical tool for demonstrating the user expectancy of certain features in a concrete product. It helps explain how different features will position a product in a different mindset in the customers' desire of it.

Its main use is to demonstrate the difference of three types of user requirements inside a product range. This is done by the evaluation of each requirement under two main criteria, customer satisfaction and requirement fulfillment. With this in mind, the three types of requirements are: Attractive requirements, One-dimensional requirements and Must-be requirements. (Elmar Sauerwein, 1996)

The must-be requirements are those the user takes for granted. They are usually not directly demanded as they are obviously expected. The achievement of these requirements does not give any competitive advantage, but failure to accomplish them will immediately take a product away from the market as users will not even consider it. E.g. A light bulb must illuminate the room.

The One-dimensional requirements are usually explicitly demanded by the customer. They satisfy him in a proportional matter to their performance. A medium class product would usually focus in integrating as much requirements of this type as possible.

The attractive requirements are those that create a strong advantage over the competition. They are not usually expected or expressed by the customer and therefore create the most amount of satisfaction over their fulfillment. Great products try to incorporate them through the push introduction of new technologies as they are excellent market differentiators.

It is important to mention that all requirements go settling down the model through time as the users start getting more accustomed to new features and technologies. This creates a continuing pressure on the market for the development of new technologies. In Figure 6 we can see the Kano model represented in a cartographic map where the customer satisfaction is on the vertical axis and the requirement fulfillment is on the horizontal axis. Attractive requirements are over the top curved line and must-be requirements are under the lower curved line. One-dimensional requirements are expected to be between the two curved lines.

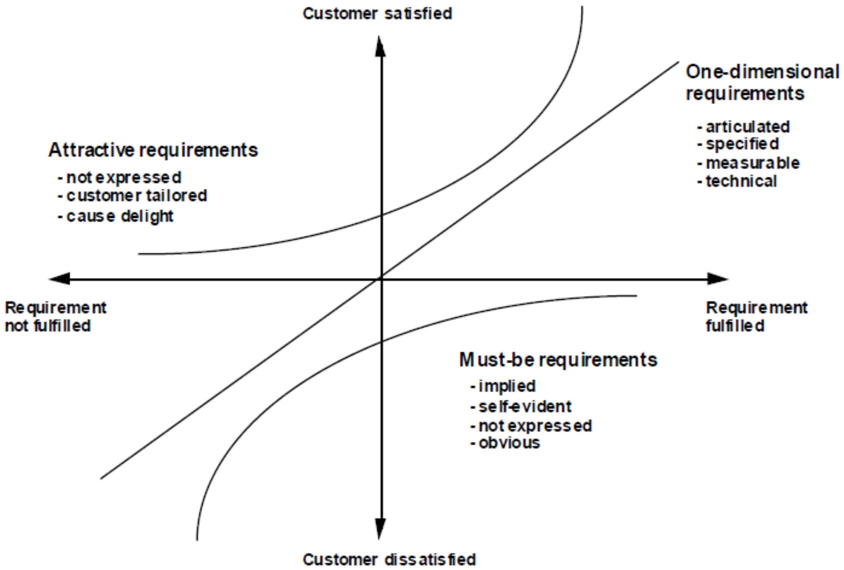


Figure 6 Kano Model (Wheelwright & Clark, 1992)

Benchmarking

Benchmarking is probably the most common practice in product development nowadays (Bergman & Klefsjö, 2010a); however it is also widely spread in areas like process improvement. The basic idea behind it is to make a comparison between other products or offers to your own. This comparison will try to identify points on which you can obtain an advantage and differentiate yourself from the rest. In Japanese the corresponding concept is called 'dantotsu' (ダントツ) which roughly means "striving to be the best of the best".

There are many different types of benchmarking and a great variety of methods for doing it. Methods usually vary depending on the product, process or service to explore and the marketing strategy of the company. A common classification of benchmarking is divided into *internal*, *competitor*, *functional* and *generic*. *Internal* is when you evaluate within the organization; *competitor* when you evaluate your opponents performance; *functional* when the comparison is not done only between yourself and the competitors but to all the market in a certain ability and a *generic* when you compare with all industry groups.

Forecasting the demand

When a new product is being planned, the stakeholders would like to know if it would make economic sense to start the endeavor. Besides the feasibility analysis which can be done in part by the SWOT analysis, it is very important to be sure it would make economic sense. One of the most important factors in the financial result of a new product is the demand that exists for such. There are many different methods for estimating the demand of a certain product but most authors agree on dividing them in two main categories: qualitative and quantitative.

Qualitative techniques are also referred to as management judgment or subjective techniques. The results are as subjective as the methods used to obtain them. It is very hard to measure the accuracy of such estimates nevertheless they show their value when little information is available on a market or where little data exists. The most common qualitative techniques are based on the opinions of management and the sales force although they can be as structured as the Delphi method. (Hutt & Speh, 2007)

The Delphi method looks to obtain consensus of the opinions of a panel of experts through a very structure method. In a simple form, it requires a panel to give an opinion or prediction of what is to happen, later the generated document is given anonymously to a second group which will analyze it and give its feedback on it. After several iterations, a final global agreement is obtained. It requires a very good and neutral coordination but it also helps to avoid the social phenomena that taint the opinion of the experts.

Quantitative techniques for demand forecasting aim to obtain well based information. These methods can be divided in time series techniques and regression or causal analysis. The first ones use historical data to project a trend. They are based on the belief that a future set of data will exhibit the same behavior of a previous set of data. This is most effective in short periods or in well know cycles.

The second approach, causal analysis, tries to identify factors that affected past sales and analyze them in a mathematical manner. It usually ends in an equation that includes variables for the most relevant factor that affect demand. Nowadays most firms combine both methods to obtain better results. (Hutt & Speh, 2007)

2.2.2 Kesselring Method

In order to help designers make decisions between several options Kesselring developed a method that would divide each alternative in several parameters. (Wim Zeiler, 2007) The original version of the Kesselring method was intended only for evaluating function and realization. In this way every possible alternative was mapped in a two dimensional space allowing the designer to easily visualize several different alternatives and take a decision with help of the graphic representation. Nowadays design decisions are made considering more than those two parameters but the Kesselring method has evolved with this new demand.

One of the most important features of this method is the assignment of different values to different parameters. It results obvious to anyone involved in a development process that not all factors of a design are equally important, therefore a different weight is given to each feature or characteristic. The Kesselring method is then used to compare between all design options using a structure that includes very different dimensions and considerations and still will be able to compare between them.

This method is usually performed with the help of a matrix that orders characteristics to grade and different design options as seen on Figure 7. The value used to compare between different options is represented by the weighted result which is calculated by obtaining the weighted average of the grades given to a certain option in all dimensions. As we can easily see, between all possible options and dimensions, we now have only one value to compare, making the design decision a lot easier.

	Weight	Option 1	Option 2
Dimension 1	W1	G11	G21
Dimension 2	W2	G12	G22
Dimension 3	W3	G13	G23
Weighted result		R1	R2

Figure 7 Kesselring Matrix

It is important to mention that the manner in which each parameter is weighted and the grade each solution is assigned to greatly depends on the people carrying out the method. To avoid personal preferences is normal to carry out the method within a joint team of experts from different disciplines. Usually the weighting dimensions are taken from the requirements and desires lists and it is recommended to only use options that previously complied to all requirements at least in a minimum way as the large amount of combinations between options and dimensions can translate in a time consuming process. (Wim Zeiler, 2007)

2.2.3 Quality Function Deployment

Developed in Japan during the late 60's, QFD presented a systematic methodology to achieve high quality products from the translation of customer demands into engineering principles applicable in all the stages of the development process. One definition of it is: "A system for translating consumer requirements into appropriate company requirements at each stage from the research and product development to engineering and manufacturing to marketing, sales and distribution." (Bergman & Klefsjö, 2010a)

It is an excellent tool that brings teams of different specialties creating a multidisciplinary group to work out common concepts. It involves four different stages:

1. Perform a market analysis to obtain needs and expectations of the customers, examine the competitors (benchmarking).
2. Identify the key factors for the success (market differentiation)
3. Translate all that information into product and product characteristics in connection with design, development and production.

The aim of QFD is to translate wants and needs (Kano model) into product and process characteristics by systematically including them in every part of the whole development process. It is very important to mention that QFD must be used through the whole development process, from design to production in order to obtain its full capabilities. It usually is presented in four main stages of the development process, consisting of: Product planning, product design, process design, and production design.

In the first stage, the wishes of the customer are transferred to the properties of the product. For this, a valuation of such wishes is performed assigning concrete values to them in a very similar fashion to the Kesselring matrix. The output of this first stage is the engineering characteristics of a product which will then be transformed in to the individual parts characteristics during the product design stage. In the third stage, product planning, the parts characteristics will evolve into the key process operations to later become the production requirements in the final stage

An obvious advantage of following this method is the early interaction between all the areas of the company involved in the project, plus it helps plan future steps while the first development is being made, resulting in a complete cross functional team working in parallel. (Bergman & Klefsjö, 2010a)

2.2.4 Dependency Structure Matrix

Also known as Design structure matrix (DSM), (Lindemann, 2009) it's a powerful tool for organizing any particular project that might need iterations, e.g. a product design project. It comes as a resource that helps large firms to overcome the challenge of reducing their cycle times. Among such challenges is the inefficient use of resources, unstable product requirements, lack of activity coordination, insufficient information about activities required information and overly ambitious schedule such that increase risk.

DSM is a lot more than just doing several activities in parallel, in fact it argues that doing several activities in parallel when there is information that one activity requires from the other will certainly result in rework. DSM on the other side brings a system approach and studies the interrelationship that exists in its parts. Considering that most of the challenges previously stated are usually resolved through iterations. Once new information is created, a previously finished activity has to be reevaluated.

There are two kinds of iterations: intentional and unintentional. The first step to reduce cycle time is eliminating unintentional iterations by organizing the activities in the right order and making sure information and resources are available when needed. The second step is to make intentional iterations faster and fewer or to aim for deeper and more conclusive iterations depending on the company strategy.

DSM is based on a matrix in which every activity is assigned to a column and a row. Diagonal elements are placeholders in a single matrix and off-diagonal elements indicate relationship between activities. Sub diagonal elements indicate feed forward information and super diagonal indicate feedback and potential for iteration and rework. Examples of these relationships can be seen in Figure 8. After the matrix is finished, there are several different algorithms that simplify it with the purpose of reducing the upper diagonal elements. In a management perspective, DSM provides information that PERT or Gantt charts are not able to visualize and cannot plan for. (Tyson, 1998)

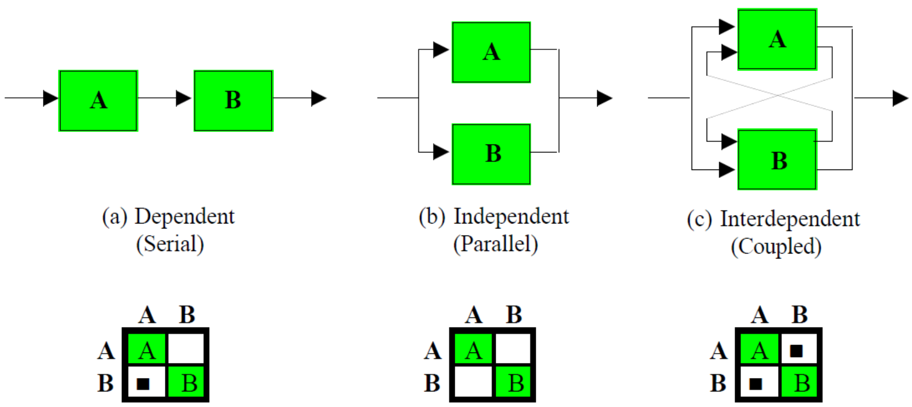


Figure 8 DSM relationships (Tyson, 1998)

2.2.5 Design of Experiments

Design of experiments is a useful tool when trying to evaluate the individual contribution of each part in a complex system, where no clear mathematical model is defined. It uses statistical analysis and it provides with relative simple math, a map for understanding the relationship of the individual elements in such a system.

This experimentation system comes from the idea that one-factor-a-time experiments brings very little information and it is not at all certain that you can obtain the most efficient results from it. Design of experiments (DoE) comes from measuring the results of combined experiments. It allows a judgment on the significance to the output of variables acting alone, as well as variables acting in combination with one another. (Bergman & Klefsjö, Design of Experiments, 2010)

In order to run an experiment using DOE several steps must be taken. The first one is to find the elements to be measured and to set the level values for each one. For every element, different levels will be defined. This is the range for which the effect of that element will be known. The second step is to lay the experimental plan is which tries to include all possible combinations of levels for all elements. Each time a combination is performed it is called a run and it creates an output value.

In the third step, the output of every run is compared to the level of each variable and a contribution effect is assigned to each one of them and to the combination of two or more elements. In other words, the average of all the runs where the level of an element is high subtracted by the average of all the runs where the level of the element is low will equal to the average contribution value of a single element.

In order to obtain the best results possible a full matrix with all possible elements and level combinations is needed, however too many experiments might be needed for that. It is also possible to run only fractions of such matrix and work from there. The fewer the runs in the experiment the less information will be available but the less resources will be used as well. (The Quality Portal, 2009)

2.2.6 Brainstorming

This is probably the most used and conventional method in any kind of problem solving session. It does not need any special arrangements and is organized as any normal meeting. It differs from normal meetings only because of the rules used for the presentation and evaluations of the ideas created. The basic idea behind brainstorming is that no idea shall be criticized and everyone present is allowed equal rights to present their thoughts. In this way, crazy ideas might leave space for increased creativity that can bring solution to the problem in matter.

When done in groups with strong diversity of skills and backgrounds the efficiency of the method increases considerably as one man’s idea can be carried by another person’s experience.

2.3 Robust Design

When a desire to make a product as reliable as possible is present, robust design is of the outmost importance. Several principles must be considered for understanding what robust design stands for. In the first place, variation, everything in nature presents natural variation. It cannot be avoided but it can be controlled. In every production system, there is always noise from uncontrollable events. However, if all this is accounted for, then the necessary precautions in the design must be made to avoid variation from preventing the product from working. This is robust design.

It is important to think about robustness early in the development process that is when the actions taken are more effective. However when decisions are made early in the process, they are usually taken while some information is missing. Robustness is more than a technique it is rather a design philosophy it is creating a process or product which will ensure a satisfactory outcome in a variable environment.

Robust design is strongly related to tolerance requirements. Just complying with tolerances does not make a manufacturing process robust. When a manufacturer tries only to comply with the required production tolerance he usually ends up making a system highly affected by noise environments, thus with low quality. It is very important to relate the output with both design parameters and noise factors.

A simple example of robust design is instantaneous soup. The instructions for making such soup are usually found in the back side of the package, they include the ingredients and the time it should take to make it, however the manufacturer must account that whoever customer makes the soup might not follow the instructions exactly, still they would be unsatisfied if it doesn’t taste nice. Robust design is applied when the soup tastes properly even if the water temperature varies or if the ratio of the ingredients added changes. In this example, the final taste of the soup is robust from the variation in the input ingredients. Of course, there is always a limit in the amount of variation a design can take before it falls out from the quality margin. (Bergman & Klefsjö, 2010a)

2.4 Project Approach.

This chapter intends to be a bridge between the theory previously explained and the actual project description. It will explain in an introductory manner, how and which methods were used and how were they applied in this particular case.

As it has previously been said, this thesis represents only part of the full development of the product. It is easier to exemplify this by using the stage-gate model previously described. By the time the thesis had started, The Emergency Housing project had already finished the stages of discovery, scoping and the business case and had started the development. By the time this thesis work had finished, test and validation was about to be concluded. It is clearly represented in Figure 9, where the green stages have been finished before the thesis started and the red stages fall outside the range of it.

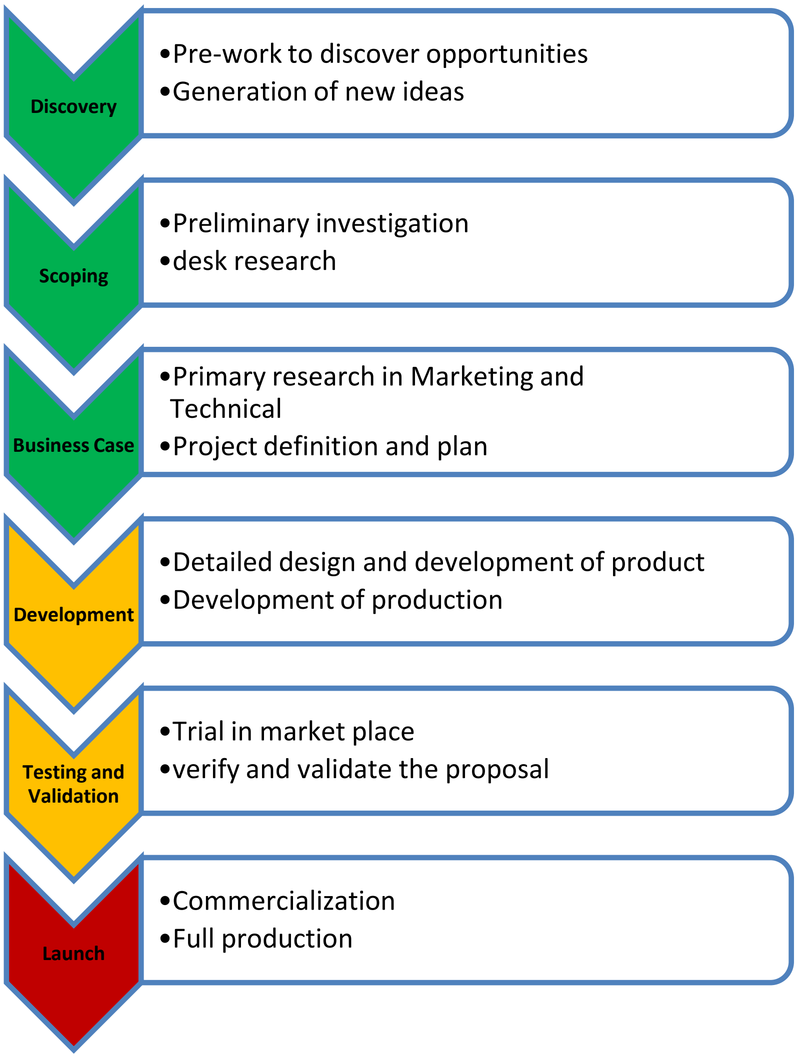


Figure 9 Stages of thesis in project

The business case was reviewed as an introduction to the development process to guide the reader into the detailed design. Although in the general process it had already been done, a small qualitative forecast of the demand is presented in this paper next to the evaluation of the users and the stakeholders. This will help understand the requirement list and the methods taken during the rest of the project. This is also where a SWOT analysis is presented. It will help explain the feasibility of the project.

The thesis focuses on two stages, Development and Testing. These particular two stages involve a great deal of methods and work. They are where the core of engineering work is performed and an excellent opportunity to use the models and techniques previously described, learned during the masters program in product development.

At the beginning of the development stage, an interrelation diagraph was drafted to explain the relationships that existed between the proposed parts. With these relationships drafted, it became obvious that the use of DSM would help preview and avoid unnecessary design iterations, thus reducing the cycle time. After solving the matrix with the help of specialized software, the order for the detailed development of the parts was planned.

During the detailed design of the parts, we will see how a particular configuration of the tent reinforcements was pursuited. For this task, design of experiments has proven to be a very useful tool as the tent is a complex system in which its elements and their relationships are deeply related to a measurable output.

Testing included several virtual simulations with two main tools. SAP 2000 was used for the structural simulation, helping to input the weather load conditions and Solid works simulation software to test the joint. Together with the virtual simulations, prototype productions were done to evaluate the proposals in a real environment, however, at the moment the thesis was finished, on site testing hadn't been performed.

The Kesselring matrix proved its value while comparing different types of anchors in order to chose a best option from those available in the market. Of course the information used in the Kesselring matrix came from a market benchmarking as well as from the evaluation of the developing tent in comparison with other solutions available online.

Section 2, Design and Development

During this section, the development and design of the product will be explained. It will start describing a market analysis and conclude with the detailed design of the project.

3. Market Analysis

In order to position the refugee properly in the market and to evaluate the critical characteristics it should contain, market information was analyzed using different tools and strategies. Information was recovered from official sources like annual reports from international humanitarian organizations like the United Nations or the Red Cross.

Another source of information is the open information some organizations have released about similar products on the market. This is the case of the Shelter Center or the Sphere project, which recollect information from manufacturers around the world to present a benchmark of the best products around and do an objective evaluation of them.

Among the huge amount of information available on the published sources around the internet and journals, it was only considered relevant such that came from produced and tested products on real situations. Also a strong emphasis was made in the official publications of the United Nations and the International Federation of the Red Cross, the two main actors in the distribution and allocation of shelters, which represent over 50 % of the market

In every market study it's important to differentiate between the final user and the stakeholder in order to fulfill the specific requirements each would have. In this case the user would be the people living in the shelters, the refugees; while the stakeholders are the organizations providing the shelters and the manufacturers.

This discrimination between user and stakeholder lets us distinguish and predict different requirements based on the usage they give to the shelters. On one side the stakeholders are going to be especially interested in the manufacturing capability and logistics issues, while the final users will be more focused on life length, space of living, adaptability to their customs, etc.

It is important to mention that Formens Hus is a non-profit organization and the reason a market analysis was conducted was because of the advantages it provides in developing properly the design, not because it looks to generate a profit. It should also be mentioned that although the design is open source, the manufacturers around the world must have a profit margin in their operations. A concrete business plan is a fundamental pillar for sustainable development.

Cultural acceptance is not the only important hallmark for appropriateness of products for humanitarian assistance. Other characteristics concern durability, logistical qualities and clarity of use. And last but not least, the commercial interest of the manufactures also plays an important role in the emergence of a successful design. (Kemenade, 2007)

Figure 10 Stage one tent in Dadaab, Kenya Mobilephotos@heidenstrom

3.1 Strengths Weaknesses Opportunities and Threats

A SWOT analysis is a strategic planning method which helps to analyze in an orderly fashion, characteristics that affect a project both from within the firm and from the external environment. It divides these factors in strengths, weaknesses, opportunities and threats and from this it lets you understand the information a lot easier.

The strengths for the project are:

- Excellent pool of knowledge from different experts globally in several fields of study
- Great contacts around the Swedish industry
- Sponsors from several places
- Sufficient recourses for prototyping
- Compromise and determination from participants
- Small well organized groups and roles
- Strong experience in the technology needed for the project

Internal weakness

- It is an open source project so rewards are small
- Short period of time for development
- Lack of experience in this branch of products

External opportunities

- Huge and growing market
- Lots of space for improvement
- Clear demand for a new solution

External threats

- Strong competition from similar agencies
- Results are open for competitors to see because of the open source nature of the project
- Prices of materials have increased considerably
- The manufacturing process is expensive
- Logistics are complicated

The main complications the project will have are based on materials, manufacturing and logistics. The technology and skills needed to develop the shelter are at hand even if the time available is limited. It is a big growing market which represents an attractive opportunity for the interested manufactures but at the same time it is an area run basically by NGOs whose lack of high resources limits the development of the product. All together this represents a great opportunity for new designs and ideas to be tested in a demanding environment bringing a better life to those who need it desperately.

3.2 Prediction of Future Market

Any given year, millions of people lose their homes and belongings in natural disasters and conflicts. (Kanter & Karlsson, 2010) At the moment there is over 15 million internally displaced people (IDP) and over 11 million Refugees around the world, from where at least 5.5 million live in camps for more than 5 years. (Shelter Center 2009) A reference map of the distribution of the refugee camps around the world can be seen in Figure 12 and Figure 11.

Table 1 Refugees and IDPs by region under UNHCR (UNHCR 2009)

	Africa	Europe	Asia	America	Total (Millions)
Refugees	2,4	1,6	6,5	1,0	11,5
IDP	7,6	1,6	3,7	3,0	15,9

When the relevant authorities are unable and/or unwilling to fulfill their responsibilities, they are obliged to allow humanitarian organizations to provide humanitarian assistance and protection. (The Sphere Project, 2004) In practice the humanitarian relief is now dominated by a few large actors. Mainly the UN bodies, followed by the Red Cross represent the world contributions to humanitarian relief. The expenditure of these organizations can be seen in Table 2.
(GHA 2010)

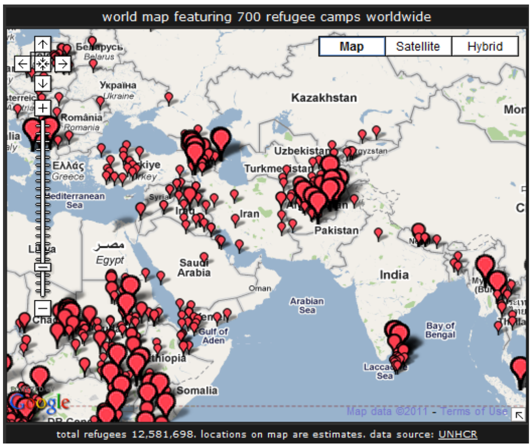


Figure 12 Refugee camp distribution in central Asia

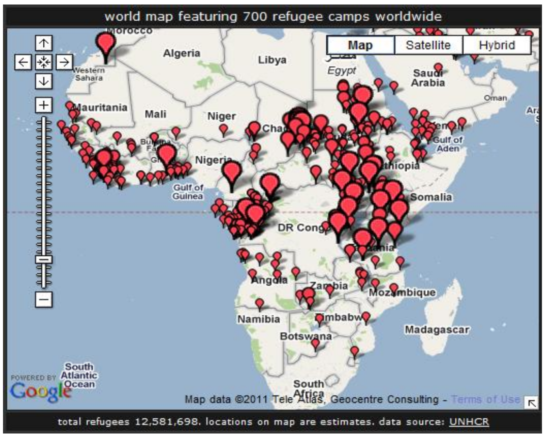


Figure 11 Refugee camps distribution in Africa

Table 2 Expenditure in Euros per year of most of the humanitarian organizations in the world

	2005	2006	2007	2008	2009
UNHCR	1096.00	1080.00	1286.00	1598.00	1715.00
UNWRA	75.62	103.68	138.53	204.94	N/A
UNICEF	N/A	2344.00	2517.00	3098.00	3298.00
IFRC (CHF)	479.07	534.10	404.89	506.55	475.56
ICRC	N/A	753.00	840.00	1000.00	1000.00
MSF (E)	509.30	559.90	557.40	648.20	N/A
OXFAM	N/A	638.25	704.53	771.75	N/A
CARE	564.94	645.62	607.84	673.21	708.39
Save the children	N/A	N/A	361.55	462.79	465.66
World Vision	1970.00	2100.00	2220.00	2570.00	2580.00

The total procurement of all the organizations has always been short to that of the demand. Even though the budget for humanitarian relief increases every year, nevertheless it is not predicted to ever be more than needed. From this amount of resources a total 5 to 15% is used for shelter production which has been limited to a few suppliers around the globe, mainly in China and Pakistan.

Humanitarian organizations usually have a stockpile ready for immediate reaction to emergencies and look to have strong suppliers able to cope with large demands in little time. In the future we can see a trend in enlarging this stockpiles and diversifying the amount of suppliers.

3.3 Stakeholders

From the position and perspective of this work several levels of stakeholders are present and should be considered. Final users, interpreted as those that would live and assemble the tents, are described in the next section while here only stakeholders are described.

Defining the stakeholders helps developing requirements for the tent. Although the main focus is always on the final users as they are the purpose of the project, stakeholders cannot be disregarded. As explained in the introduction, the project of "The Emergency Housing Project" is founded in part by the IKEA foundation and run by Formens Hus a nonprofit organization that evaluates different shelter and relief housing solutions for refugees around the world. In case of being purchased as a product it would be installed and distributed by other international NGOs like UNHCR and the International Federation of the Red Cross (IFRC).

The UN and the IFRC, together they represent the largest customers of emergency relief solutions existing in the world. Although they are very different organizations, several similarities can be found in their operations. Both organizations have supply stockpiles in strategic positions around the globe with the capacity to provide immediate assistance in case of need. In the case of the UNHCR, it owns stockpiles in Copenhagen and Dubai and is now in a capacity to mobilize Emergency Response Teams (ERT) within 72 hours to respond to the immediate needs of 500,000 people in a humanitarian emergency. (UNHCR United Nations Refugee Agency, 2009) This requires a very large space for storage, making a strong pressure on the diminishing of volume for our product.

In the case of UNHCR for example, they have stockpiles in Denmark and the Arab Emirates with a capacity to assist 500,000 people in the case they are needed. The contracts with their suppliers usually vary between 3 and 5 years. (UNHCR United Nations Refugee Agency, 2009) In the future we can see a trend in enlarging this stockpiles and diversifying the amount of suppliers. The market will clearly expand.

The IFRC works on base to their local and national parts. Each one of them prepares themselves based on their recourses and capacity. Several proposals of emergency response teams formed by several countries in one region are now operating. To each of these individuals, the same requirements of volume of storage and weight are of the outmost importance. In 2009, the IFRC opened a new humanitarian logistics centre on the Canary Islands (Spain). The main purpose of the new centre in Las Palmas de Gran Canaria is to store and dispatch emergency aid to the survivors of humanitarian crises. (IFRC International Federation of Red Cross and Red Crescent Societies, 2009)

Being international nonprofit organizations, the demand upon them to control their expenses and acquire only the best products that comply with international standards on security and quality, translates the same demands into the tent. It must act in accordance with all safety and security regulations as any first class product. The methods these organizations use to respond in case of an emergency strongly determined the tent characteristics, its requirements and its development.

3.4 User Analysis

Defining the final user and the way it will interact with the product is a very important step in the process of development. In this case the stakeholder was defined as the organizations providing the tents, and the user as those groups or individuals, who will manage it on site, assemble it and live in it.

In the year 2004, the United Nations High Commissioner for Refugees (UNHCR) estimated that there were 20 million refugees living worldwide. In addition, 25 million people were displaced within the borders of their own countries and were thus classified as Internally Displaced Persons (IDPs). (Corsellis & Vitale, 2005)

They are the single most vulnerable population in the world. During displacement, IDPs are often subject to physical violence; women and children are particularly vulnerable as they are at the highest risk of losing everything. Most importantly, IDPs are unlike refugees, in that they do not have legal status protecting their lives and rights. (UN-HABITAT, 2005)

What does the tent contribute to the lives of IDPs and refugees?

A tent provides several things beyond the obvious to the IDPs and the refugees. On the first place is the protection from the environment. A transitional shelter can greatly improve the overall health of a population by protecting its inhabitants from the cold and hot and the spread of diseases.

When the most of extreme situations has been controlled, inequity comes as a detonator for desperate people to achieve a better life. The introduction of a tent, that later becomes a home helps reduce this gap between populations and greatly reduces disputes and increases safety and security. In its most obvious sense, it is security of land and of property tenure that gets protected. There are several cases in which the populations reject the shelters as they cannot move with them.

The construction of shelters also provides the basis for economic recovery and the creation of local governance which basically translates to conflict mitigation and peace building; gender issues can also be addressed by the installation of shelters. Women rights get protected and families can achieve a degree of normality in their lives.

3.4.1 Lifespan Usage

Refugee camps evolve during time. There is a strong difference in the sight, organization and demands a refugee camp and its inhabitants have through the first years. In this dynamic evolution, housing is the most relevant change a family will have and the most determinant of their life quality as well. This puts pressure on NGOs to ensure that what is provided to the families will work for long and it will satisfy present and future demands of the affected population.

The rate at which the priority demands change is very high at the beginning and it diminishes while time advances. We can see in several manuals and guidebooks that the most important matter to cover is health and security. (UNHCR, 2007) Shelter is strongly linked to both of them.

As it is to be expected, the demands on shelter vary considerably between places depending on weather, culture and terrain. However, a general outline of the evolution of a shelter can be traced. It is always important to remember that different relief organizations have different ways of working and that the physical standards of shelters work different for every case and situation. In this thesis, a general outline of how it roughly works on most situations will be explained.

The first step is to ensure security. The responsible NGO who will install the refugee camp must ensure that basic security will be provided to the people in the camp. The situation is analyzed as much as possible while the first response is being sent. In the first 48 hours, the focus is always in procuring security and basic health services through the installation of control points and basic health facilities to treat illness.

The amount of people affected by these tragic situations is usually very large. The first response will usually be flown from the storage facilities around the world limiting the weight and volume capacity of the transported goods. It is very hard to transport full housing for the displaced by air so that basic materials are sent. Normally these materials encompass blankets and plastic sheeting or tarpaulin which enables the fast construction of basic shelters.

Accommodation made of plastic sheeting and tarpaulins are not intended nor do they have the capacity to last for a very long time. The second stage is the installation and construction of temporal housing made of materials similar to a camping tent. These new shelters are usually sent by boat and arrive in the next weeks after the refugee camp has been installed. The living condition of refugees improves considerably with this kind of shelters as they provide a degree of security and procurement of possessions. Nevertheless, a common problem is that the material temporal shelters are made of, usually runs off and breaks, leaving its inhabitants with the need for constructing improvised unsecure housing.

After two years the incorporation of local materials into the construction of housing will be predominant. Probably some materials from the previous shelters will be used for the new housing like the plastic sheeting in the roof or the floor however little will remain of them forcing the families to reconstruct their homes in poor conditions.

In Figure 13 we can see how the immediate structure of plastic sheeting evolved in time to become a house made of local materials. This process takes several years but it helps activate the local economy through the creation of jobs and market activation. (Ashmore, 2004c)

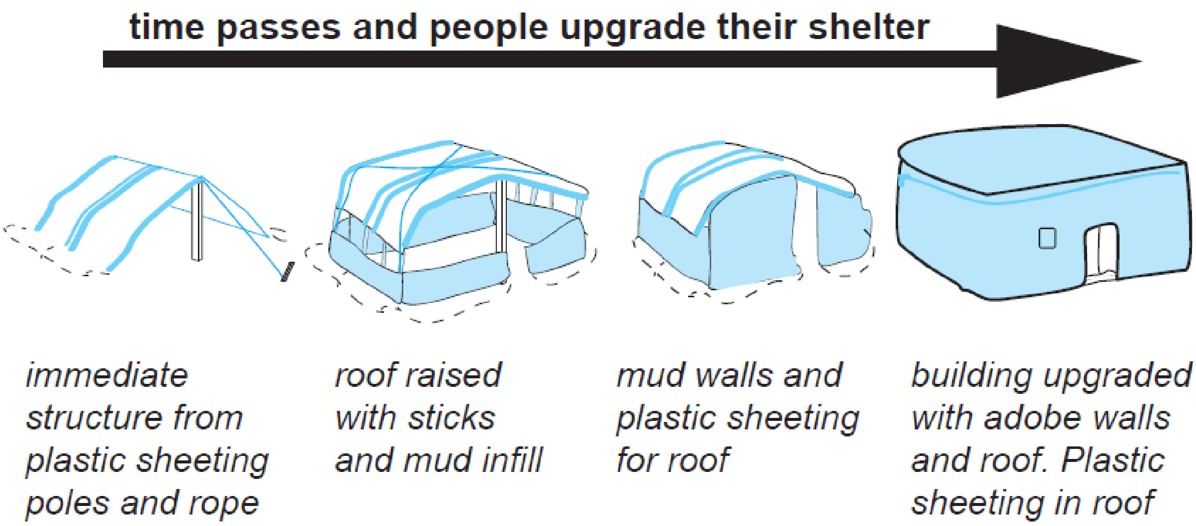


Figure 13 Example of how people might develop materials delivered through emergency assistance into more permanent structures

The proposal of the emergency housing project is to provide a temporal shelter that can use local materials and grow with them into a permanent solution capable of providing security and dignity to the people living in it. In the shelter distribution process it will be sent to the camps in the second stage, when temporal shelters are sent, for roof and walls, probably the plastic sheeting or protection tarpaulin will be used. In a later stage, hard panels will be sent to the camp to be incorporated to the tent providing a solution that will be able to last for several years.

3.5 Benchmark

At the moment several different models of shelters can be found around the world, however the ones that make it to the market and are used by the leading organizations are quite limited. Which shelter is used depends mainly in the recourses available and the providing organization, as each organization has different objectives and standards of operations and some of them use different kinds of shelters according to the development of the need. In a general perspective, most shelters used can be divided into four major types. (Formens Hus Foundation, 2009)

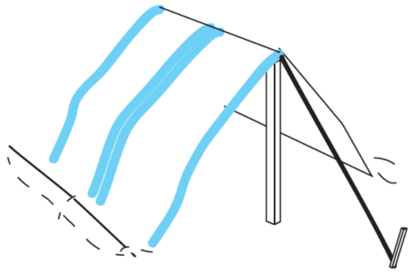


Figure 14 Shelter Kit + Tarpaulin

Shelter Kit + Tarpaulin. This is meant for fast reaction and to ensure fast relief to the largest amount of population possible. It is usually used in the most urgent moments and their results in the short run are very effective thus becoming a very popular first choice. In the medium and long run however, the vulnerable conditions of life it can offer to its inhabitants is not sufficient and the materials usually break. On the positive side, the materials included are versatile and can be used for a great deal of future applications.

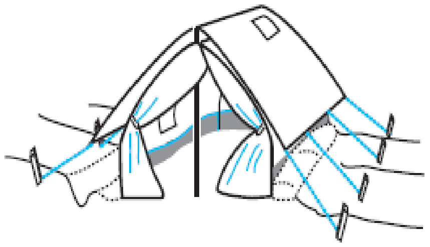


Figure 15 Canvas Tent

Canvas Tents are the next most used solution. They consist on a rigid frame that can or cannot need extra tensors for stabilizing. Over the frame, a custom made flexible cover gives shape to the tent. It is usually made from either plastic or cotton fabric. They frequently bring a good cost/weight/size value as they can be easily packed, transported and manufactured. The developed solution is a modification of this design.

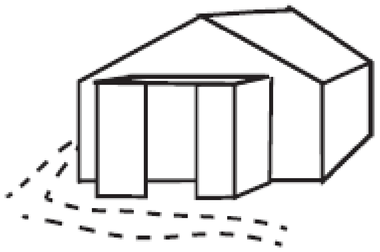


Figure 16 Hard Shell Shelter

Hard Shell shelters are the closest thing to a house that exists on the market. They seem to be a very good option however they are very bulky to transport and extremely slow to build, plus they lack the temporarily look when wanted to be constructed in areas where there exists some land property issues.

The last solution is the shipment of standard components for house fabrication. This gives the local people the opportunity to develop within their own architecture and customs plus boosting local economy through the contract of local workforce to construct the houses. The downside is that they can't be relocated, skilled labor is required to build them and there might be some land right issues for the settlement of the camp.

A benchmark rating was performed by Formens Hus to evaluate these options. It is based in the most important requirements shelters are evaluated by. (Formens Hus Foundation, 2009)

Table 3 Example of Kesselring matrix used for benchmark rating of actually used tents

Shelter type	Price	Volume	Weight	Deployment	Comfort	Adaptability	Life span	Sum
Evenshelter	4	4	4	4	1	1	1	19
Transhome	2	3	3	3	2	3	2	18
MADDEL	1	2	2	2	3	2	3	15

From this evaluation, we can appreciate that the Evenshelter tent is the one with more space for improvement. The four most important characteristics are: price, volume, weight and deployment. Comfort, adaptability and life span can be easily upgraded in this kind of tent by using different materials or slightly modifying the geometry and design of the parts. Based on this Benchmark, it would be clear that a canvas tent is probably the best way to go. All images taken from (Ashmore, 2004d)

3.5.1 Similar Projects

Several similar projects to the one of Formens Hus were evaluated to find the right market differentiation factors that will bring success to the project. In this section, some of these projects are shortly described and evaluated against the proposed solution.

Evenshelter concept by Evenproducts

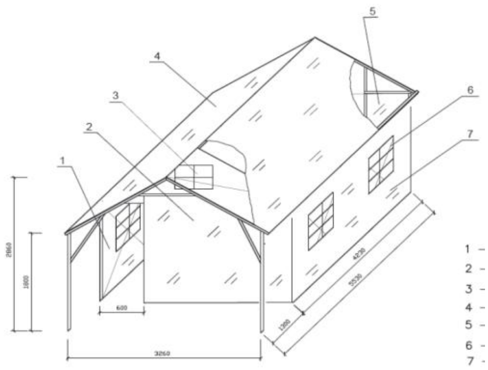


Figure 17 Evenshelter by EvenProducts

Light, easy to build and made with standard components this solution resembles strongly to the emergency housing project. It complies with most of the requirements stated by the UN and IFRC. On the downside, it includes a lot of complex parts, demanding several manufacturing operations thus increasing its final price. The packaging of it is also very bulky and there is a large possibility of losing the small parts it is made of. The whole tent is assembled by the use of bolts and screws which can also get lost or break and demands the user to have the proper tools for assembly. (Evenproducts, 2010)

TransHome® by H. Sheikh Noor-ud-Din & Sons

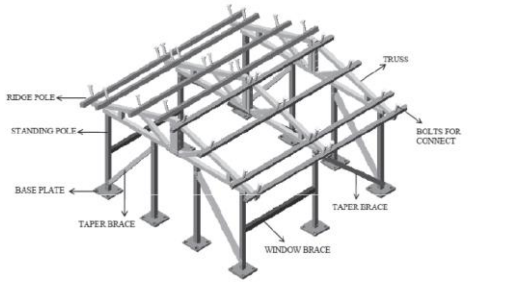


Figure 18 Transhome by Sheikh Noor-ud-din & Sons

This is a very sturdy solution, that if everything works fine it will provide a very long lasting solution that still keeps the property of being disassembled and reinstalled somewhere else. On the downside it has way too many different parts, the parts are very complicated and it is obvious that during assembly several mistakes will be made consuming a lot of time. The amount of parts is also such that it cannot fit inside the UN pallet and therefore impossible to transport with the actual standards.
(Dinsons Manufacturing Group, 2010)

MADDEL transitional shelter

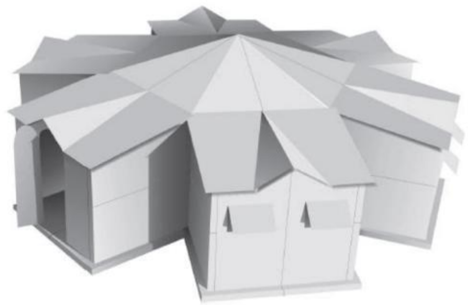


Figure 19 Maddel transitional shelter.

This prototype is based on the connection of several foldable modules that interconnect to create a shelter made of individual rooms. On first sight it looks like a very good idea, easy to assemble and easy to transport, however the sizes of the packed tent are considerably bigger than the volume allowed by the UN standards. It also lack the capacity of integrating into different cultures to become a home, nevertheless it is easy to see it becoming a clinical health unit for its capacity to remain clean inside. (Maddel International, 2011)

Hexayurt

Figure 20 Hexayurt

When researching about possible alternative products the Hexayurt which show potential. The shape is very similar to the houses found in East Africa and the Caribbean plus it can be made of several different materials. The problem however is the speed on which it can be sent to the conflict area. It will not fit in the pallets so an initial tent for immediate response is necessary.
(Hexayurt Project, 2009)

After comparing all of these projects, it is clear that the differentiation factors will rely in the bulk to carry the tent, the speed on which it can be delivered, the compliance to the regulations stated by the relief agencies and total cost. Most ideas abuse the creativity of their designers forming strange shapes that do not resemble houses and therefore are uncomfortable to live in. (Islam, 2000) Others forget that the labor available might not be skilled enough to properly assemble a complex tent or that the lack of specific tools will not let them assemble the tents. If the Emergency Housing Project by Formens Hus is to be a success, it must comply with all standards and specifications plus consider all the factors mentioned before.

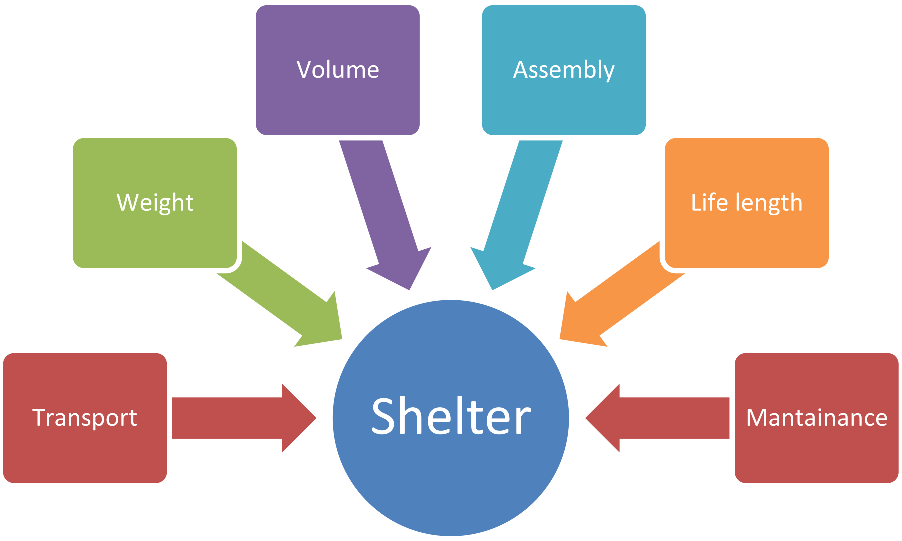


Figure 21 Shelter benchmark qualities

4. Requirements

Requirements for the project came from very different places; they could be social, manufacturing, stacking, usage, legal, etc. In this thesis the requirements stated by several actors around the product are tried to be simplified to obtain what was most important to the success in implementing it.

The kind of requirements stakeholders present is quite different from that of the final users. The NGOs because of their operation are more interested in production capacity, price, time of response, storage volume, weight, etc. On the other hand, users will be the reason for requirements like assembly easiness, transport, life span and its capacity to resemble traditional architecture and to include local materials and be fixed on site with them.

Some of the largest organizations in the world have already stated more or less clear requirements for the use, fabrication and installation of tents for emergency relief around the globe. These documents serve as guidelines for minor organizations and designers. The most important ones are the UNHCR Handbook for Emergencies, the complete list of tent requirements can be accessed in Appendix B.

Other NGOs specialize in gathering information from smaller companies and designers, and then they compare them with the solutions actually used. This makes the path for improvement a lot easier and accelerates the cooperation between the designers and the relief organizations. Some examples of the mentioned are The Shelter Centre, The Sphere Project and Formens Hus. Their list of requirements is displayed in Appendix C and Appendix D

In this case Formens Hus and the manufacturers introduced new guidelines to obtain an outstanding design. This requirements state the way the product will try to be more competitive in the market by offering new features and capabilities that the existing solutions lack.

In this section the requirements are structured from three different perspectives. Social requirements are based on how people live within the tents, how they adapt it and if it responds to the needs of the required populations in a human manner. The engineering requirements address the technical part; they state the measures on which the tent will be evaluated to ensure its safety, resistance and overall stability. The environmental requirements couldn't be left behind and a general overview of the impact the project has on the surroundings are explained here. They are based on the production methods, durability and materials used.

The requirements presented are taken directly from the principal organizations manuals however, the order is changed to better adapt to the layout of this project. Before the list of requirements, the guidelines of Formens Hus to improve the product are explained and presented as a list of desires.

4.1 Social Desires and Requirements

Stating and evaluating the social requirements is not within the spectrum of this project, however the importance they have on the design cannot be disregarded. For this reason the most important requirements declared by the stakeholders through several publications and official documents are mentioned in this work. (UNHCR, 2007)

The most useful requirements for the development of the project are those that explain the usage of the tent through its lifecycle. From the moment it is manufactured and stored, through its employment as a home for several years until its disposal. Most requirements covering manufacturing, storing and transport are covered in the next section 4.2. In this section, the requirements for the tent to become a home are covered.

When required, a tent is more than just a temporary settlement of pipes and tarpaulins; it is the home of a family (Islam, 2000). It must provide the basic standards to be so. When designing the tent, it must comply with the restrictions the provider organizations stated while at the same time allows for it to be culturally adaptable for the people living in it. An example of this could be taken from Islamic religion, where the position of doors, the size and height of windows and the orientation of a house should not cause harm to the neighbors. (Islam, 2000)

It is impossible to predict where a tragedy will happen and hard to design something that is universally accepted, nevertheless an effort to create a neutral convenient design must be done. An individual design, customized for each part of the world and every culture would be impossible to produce and distribute on time when needed. However, part of the cultural differences between the places it shall function, can be resolved by allowing certain flexibility in the design. If the final product is capable to adapt to different individual family requirements by small modifications in the construction then a great step towards acceptability will have been made. For example, the capacity to extend the tent to create a small side kitchen or a place to store goods, or being able to divide the tent allowing parents and children to sleep in separate rooms as well as women from men are very simple requirements but they must be considered in the tents design.

Based on this input, the list of the social desires from Formens Hus is as follows:

1. It should allow modifications done by the local users.
2. Different local materials can be incorporated into the structure.
3. Capacity to divide into several rooms
4. Ability to expand to more rooms
5. The position of the door should be flexible
6. Flexible geometry

4.1.2 List of Social Requirements

Sphere Project

- The initial covered floor area per person is at least 3.5m2
- The covered area enables safe separation and privacy between the sexes, between different age groups and between separate families within a given household as required
- Essential household activities can be carried out within the shelter
- Key livelihood support activities are accommodated where possible
- The design of the shelter and the materials used are familiar where possible and culturally and socially acceptable
- Alternative materials required to provide temporary shelter are durable, practical and acceptable to the affected population
- The type of construction, materials used and the sizing and positioning of openings provides optimal thermal comfort and ventilation.
- Locally sourced materials and labor are used without adversely affecting the local economy or environment.
- Locally derived standards of workmanship and materials are achieved
- The procurement of materials and labor and the supervision of the construction process are transparent, accountable and in accordance with internationally accepted bidding, purchasing and construction administration practices.

UNHCR

29 The design shall allow for the introduction of fuel burning stoves, including a fireproof and waterproof flue manifold.

49 Shelters shall not involve materials that are toxic to humans, even when cut or modified for later re-use.

53 Cultural and political sensitivities shall be taken into account, for example in the use of colors used in national or factional flags.

54 It shall be possible to sub-divide the internal volume in order to increase visual privacy, whilst maintaining cross-ventilation.

55 A fully closed shelter shall allow sufficient light to enter without compromising privacy.

56 At night, it shall be possible to use artificial lighting within the shelter without compromising privacy.

61 The design shall facilitate the local adaptation of wall and roofing materials, such as mud brick side walls, local matting, or thatch.

4.2. Engineering Desires and Requirements

Social requirements are usually the most important ones when designing for a user-centered approach (Islam, 2000) however it is engineering requirements that trace the path the detailed design and manufacturing of a product will follow. This case is not different. As stated at the beginning of the project, the user is the most important factor to consider.

For the construction of refugee camps, usually only a very limited group of people is trained in installing the tents and the whole organization depends on easy and fast transmission of information from the camp leader to the rest of the community. For this matter the installation should be obvious to whoever is building the tent, none or minimum instructions should be required to understand its function and avoid assembly mistakes.

Several organizations have stated their own requirements for tents and refugees used for emergency relief. All of these were considered as they must be met if the solution is ever going to be used by one of the mentioned organizations but besides the final users and their providers, there are other organizations to think about. Engineering requirements must satisfy the organizations responsible for the manufacturing, assembly, transport and structural needs.

For the purpose of organizing the requirements in an easy manner, the tent was divided into different parts. This separation is easily done as there are only four major components to be considered by this list of requirements: *anchoring system, cover, structure and joints.* A graphical description of them can be consulted in Appendix D.

The anchoring system is the use of devices that will allow the tent to be positioned in a stable way on any terrain. *The cover* and its fastening to the structure, although not covered in this work, is the material used around the structure to prevent the user from the weather conditions in the exterior. The joints are the parts required to assemble the different pipes of the structure together. The structure is considered to include the geometry, the reinforcements it shall need for sustaining the loads, and the pipes.

Cross bracing, however, is a part that was included later in the process and after the theoretical background, it was a very easy part to develop, therefore its requirements were permeated directly from those of the whole project.

Joints and anchors are part of the overall structure, therefore it is considered that they must comply with the structure requirements and no individual requirements have been written for each one of them. Nevertheless, desires can be individual and a list of desires is available for them.

4.2.1 Anchor Desires

The anchors are the way in which the tent fixes itself to the built position. This fact makes them a part of the outmost importance in the development of the tent. They must be considered in the design of the pipes, the cover tarpaulin, the hard panels and the tensors. With this in mind, a set of requirements must be settled before the design and production of both tent and anchors.

To better state the requirements it was necessary to consider the context in which the part is being used. Even with instructions, some mistakes in the location of the tents might be made, for example: After positioning the first tents, its normal that the refugee camp changes size or new spaces are needed to install larger structures like schools or community centers, therefore it is important to assure that the anchors can be removed without damaging them and be easy to be reinstalled in another position.

The tents evolve during time, as requirements for larger spaces emerge or new materials are incorporated to them. This puts a demand on the anchors to be able to adapt to such changes and still perform safely. The anchors must be adaptable to multiple usage conditions.

It is impossible to predict where a refugee tent will be needed in the future, so the uncertainty on what terrain the anchor should work on drives the need of having a design that will perform correctly in most types of terrains around the world. However, some modifications might be needed and opening the design of the pipes to let space for different types of anchors which might perform better on specific circumstances is a directive.

All this considered the list of desires for the anchor is as follows:

1. They must sustain all operational and installations stresses
2. Support corrosion for all its life length
3. Safe to install
4. Safe once installed
5. Allow for repositioning
6. Should be installed with minimum tooling
7. Support mistreat
8. Easy and obvious how to use and install
9. Must be dynamic and serve for multiple purposes e.g. restructuring of the tent, increase in size.
10. Only one type of anchor should be used for the structure of the tent
11. One design should work in most terrain conditions.

4.2.2 Joint Desires

Although the joint might be considered just part of the structure, just as the anchors, it is a part that because of its importance it needs special delimitations and requirements. Some of the great advantages of the tent rely in the design of the joints. The joints must permit the structure to be made entirely of the same material, to modify the geometry of a single tent or to allow for larger structures and buildings if needed.

The joints should be made in the most cost-effective way and this would result in a design that requires a small number of operations and would allow for big tolerances in its manufacturing. Tooling should also be considered. Even if the tooling investment is only once, in case of having several production sites, it is important to be able to make the tooling required for production in a fast and easy manner. The overall requirements are also considered for the joint; it must be light and allow for small packaging.

There are no special requirements for the joints found on the catalogues and manuals from the NGOs and little attention is put to this essential part of the tent by the other manufacturers. Joints are responsible of the easiness of assembly; the building time, the capacity of repair on site, the structural behavior, etc. Considering this, the list of desires is as follow:

1. Should be as light as possible
2. Resist the loads sustained and expressed by the overall requirements.
3. Be packed as compact as possible
4. In case of failure it should be easy to repair, e.g. Welded
5. It allows expansion of the tent
6. It allows different geometry configurations
7. Braces should be attachable to it
8. All structure pipes should be attachable to it
9. One joint design should be enough for the whole tent.
10. Should be installed with minimum tooling
11. It should be quick to manufacture
12. It must be obvious to assemble without any instructions.

4.2.3 Structure Desires

All tents used now in the market must fulfill the requirements which are established by the NGOs and governments. However, if the tent is to be a better product, new desires have to be drawn to obtain the most wanted advantages.

The new requirements were developed based on the experiences of the most important emergency relief organizations in the world. Several critical details in the actual solutions make it possible for a new more competitive product to arise.

A list of the possible requirements was stated at the beginning of the project and evolved with the development of the product. At the moment of writing this thesis, the desires were as follow:

1. The structure must be as light as possible.
2. The maximum weight of the structure is that of the actual solution
3. The structure should be packed in the smallest possible bulk
4. The maximum volume of a packed structure is that of the actual solution
5. It allows repositioning of the whole tent
6. It should be functional for 5 years minimum
7. It allows expansion of the tent
8. Different geometries can be formed with it
9. Hard panels and soft covering must be attachable
10. It can be repaired and maintained with local resources and skills
11. Parts are exchangeable between different tents.
12. Its manufacturing must be fast and cheap. Special prearranged suppliers may exist.
13. Replacement for damaged parts should be available with easiness.
14. It must improve its inhabitants lives

4.2.4 List of Structural Requirements

Sphere Project

- Construction and material specifications mitigate against future natural disasters.

Shelter Centre

- Complete package has a mass between 40 kg and 80 kg
- Total shelter is in one package which can be broken down to smaller packages, suitable for transport for 2 people
- Complete shelter has packed volume between 0.3m3 and 0.5m3.
- Longest dimension of packed shelter is no more than 200cm.
- At least 4 packed shelters can fit onto a 120x80cm Euro pallet.
- The packed shelters can be packed vertically onto a 120x80cm Euro pallet.
- The shelter should be of sufficient size to house a family of 5, with between 3.5m2 and 4.5m2 of covered living area.
- The standing height of the covered space is a minimum of 180cm over at least 60% of the covered floor area.
- There are no guy ropes or other trip hazards around the shelter.
- The shelter can be distributed as a complete package, ready to put up, with all components included and all required tools.
- The frame is strong enough to support 6 to 8 hanging live loads of 30kg.

UNHCR

1 A complete shelter package shall have a mass between 40kg and 80kg.
2 The total shelter shall be in one package which contains smaller packages broken down into parcels of weights suitable for transport by two people.
3 A complete shelter package shall have a packed volume between 0.3m3 and 0.5m3.
4 The longest dimension of a packed shelter shall be no more than 200 cm *(perhaps 220 or 228 cm, currently under revision).*
5 It shall be possible to fit at least four packed shelters onto a 120 x 80cm Euro pallet.
6 It shall be possible to stack the packed shelters vertically onto a 120 x 80cm Euro pallet.
7 It shall be possible to keep shelters in storage for at least five years without damage or changes reducing the functional capacity.
14 The shelter shall be easy to obtain from different manufacturers under competitive bidding.
15 The shelter shall be capable of being produced fast enough to respond suitably to a humanitarian crisis.
16 The structure shall have sufficient redundancy so that if the covering or one fixing fails, the shelter will remain upright.
17 The erected shelter, with all doors and windows closed shall be able to withstand a wind speed of 18m/s in any direction. After application of the load, the tent shall return to its original shape and position without damage.

18 The shelter shall withstand 300 N/m^2 of snow loading without damage or changes reducing the functional capacity *(reduced from 1,500 N/m^2 due to inappropriate source).*

19 The cover shall withstand 1500mm water column minimum *(may need separate values for synthetics/natural fibers, to be confirmed).*

21 In warm, humid climates the roof shall have a reasonable slope for rain water drainage.

22 There shall be provision to trench the sod cloths into the ground to increase the stability of the shelter.

23 From moment of deployment, the structure shall last for a minimum of 36 months, the covering and liner shall last for a minimum of 18 months *(additional investigation undertaken to determine cost burden of 12-, 18-, or 24-month liner lifetime).*

24 The shelter shall withstand temperatures between -30°C to +55°C without damage or changes reducing the functional capacity.

27 The shelter shall be large enough for a family of five and have between 3.5m^2 and 4.5m^2 of covered living area.

28 The standing height for the covered space shall be a minimum of 180cm over at least 60% of the covered floor area.

33 There shall be no guy ropes, or other trip hazards around the shelter.

36 Shelters shall have a ceiling to provide an adjustable air gap for insulation and ventilation.

57 It shall be possible for two untrained adults to assemble the shelter without expert supervision.

60 It shall be possible to connect the shelter to another of the same type to increase the covered area.

61 The design shall facilitate the local adaptation of wall and roofing materials, such as mud brick side walls, local matting, or thatch.

62 The frame shall be strong enough to support the dead load of sheet roofing materials *(value to be determined).*

63 The frame shall be strong enough to support 6-8 30kg hanging live loads *(currently under investigation by Losberger).*

64 The number of different types of components shall be kept to a minimum.

65 The total number of components shall be kept to a minimum.

66 Components shall be interchangeable where possible.

67 Components shall be available globally, or appropriate materials, tools and skills should be available for their local manufacture and repair.

69 The design shall maximize the number of components and materials that can be maintained and repaired with non-specialist skills and equipment.

4.2.5 Cover Desires and Requirements

As stated at the beginning of the document, the cover of the tent is not part of the scope of this project, however it is important to consider it for the design of the rest of the tent as well as for the usage other parts might have depending on the chosen cover.

When responding to an emergency, the first materials to arrive to the required zone are usually plastic tarpaulins. (UNHCR, 2007)These are to be considered the initial cover the structure will have. Later the structure will include its own tailor fitted cover which can go in different directions.

At the moment several options are being considered. On one side are the soft materials which could be made of plastic tarpaulins or fabric covers. For these we have to consider that they are easy to tear so the structure should not have any sharp edges. Soft covers usually are tied down to the structure, making it necessary for the structure and anchors to provide space in their geometry for the knots required. On the other side hard panels are the ultimate goal of the overall project. Either made with local materials like wood or bamboo or being made of provided plastic or metal sheeting.

If the hard panels are made of wood, stone or bamboo, it is necessary for the structure to provide the sufficient stiffness for holding the weight these materials will bring plus the weather conditions of the place. If made of hard plastics or metal sheeting the structure should provide sufficient space for them to fasten. Either on the joints or on the tubes but the way these fasten must be considered during the design of the structure.

4.2.6 List of Cover Requirements

Sphere project

- The repair of existing damaged shelters or the upgrading of initial shelter solutions constructed by the disaster-affected population is prioritized.
- Alternative materials required to provide temporary shelter are durable, practical and acceptable to the affected population
- The type of construction, materials used and the sizing and positioning of openings provides optimal thermal comfort and ventilation.
- Vector control measures are incorporated into the design and materials are selected to minimize health hazards

Shelter Centre

- Minimum ventilation shall be achieved through an unobstructed aperture with a total area equivalent to 0.01m2.
- All doors and openings are adjustable to control light and heat gain or loss.
- The shelter has two opposite doors to facilitate escape in case of fire.
- It is possible to exit the shelter within 30 seconds when all doors are fully closed.
- The shelter has a 10cm vertical edge around the base of entry points to impede the entry of insects.
- Military or camouflage colors are not to be used.

UNHCR

8 Shelters shall have space to mark which particular design it is, how large the useable area of the shelter is, as well as how many people it can accommodate.

9 Shelters shall have space to mark means of transport, time in storage, and conditions of storage.

10 Shelters shall be marked with the name or trademark of the manufacturer, and the date of manufacture.

11 The shelter shall indicate that it is or isn't mosquito proofed.

12 These instructions shall be in English, French, and any other appropriate language.

13 It shall be easy to print the humanitarian organization/donor logo on the outer fly and door of the shelter.

18 The shelter shall withstand 300 N/m² of snow loading without damage or changes reducing the functional capacity *(reduced from 1,500 N/m² due to inappropriate source).*

19 The cover shall withstand 1500mm water column minimum *(may need separate values for synthetics/natural fibers, to be confirmed).*

20 The ground sheet shall withstand 1500mm water column minimum.

21 In warm, humid climates the roof shall have a reasonable slope for rain water drainage.

23 From moment of deployment, the structure shall last for a minimum of 36 months, the covering and liner shall last for a minimum of 18 months

(additional investigation undertaken to determine cost burden of 12-, 18-, or 24-month liner lifetime).

24 The shelter shall withstand temperatures between -30°C to +55°C without damage or changes reducing the functional capacity.

25 All outer fabrics shall provide a minimum resistance to natural sunlight. This requirement is deemed to be met if, after artificial weathering in accordance with ISO 4892-2 and applying the test parameters specified in Table 8, the breaking strength and the resistance to penetration by rain are not more than 30% below the minimum value applicable to the shelter.

26 Inner fabrics shall have a minimum breaking strength of 30 daN for warp and weft when tested in accordance with ISO 13934-1 or ISO 1421.

30 It shall be possible to insulate the floor, walls and roof of the shelter.

31 Provision will be made for semi-enclosed and shaded cooking areas and provision for fixed minimum ventilation of the interior, to reduce cases of Acute Respiratory Infections (ARIs).

32 Storage pockets shall be integrated into the inner liner of the shelter.

33 There shall be no guy ropes, or other trip hazards around the shelter.

34 Minimum ventilation shall be achieved through an unobstructed aperture with a total area equivalent to $0.01m^2$.

35 Design shall allow for maximum and minimum air changes per hour to avoid discomfort of occupants, air changes per hour should be not less than 7, but not more than 14.

36 Shelters shall have a ceiling to provide an adjustable air gap for insulation and ventilation.

37 All doors and openings shall be adjustable to control light and heat gain or loss.

38 In hot, dry climates the shelter should have a double-skinned roof with ventilation between the layers to reduce radiant heat gain. The distance between the layers should be at least 100mm.

39 In warm, humid climates the shelter design shall maximize air flow.

40 In cold climates, air flow through the shelter shall be kept to a minimum, while also providing adequate ventilation for space heaters, or cooking stoves.

41 In cold climates, the shelter shall have internal compartments in order to minimize heat loss through infiltration.

42 The shelter shall have two opposite doors to facilitate escape in the event of fire.

43 It shall be possible to exit the shelter within 30 seconds when all doors are fully closed.

44 The shelter shall not ignite when tested in accordance with ISO 6940 and exposed to a test flame for 10 seconds, in the new condition and also after artificial weathering in accordance with ISO 4892-2.

45 All doors and openings shall be protected against insects.

46 The shelter shall have a 10cm vertical edge around the base of entry points in order to impede the entry of insects.

47 The shelter must be mosquito proofed in an area long and broad enough for the intended occupancy to sleep in.

48 There shall be fixings for additional or replacement mosquito nets to be hung.

52 Military or camouflage colors shall not be used *(categorical restriction on green, beige and white removed).*

53 Cultural and political sensitivities shall be taken into account, for example in the use of colors used in national or factional flags.

4.3 Environmental Desires and Requirements

Environmental requirements are usually disregarded by the humanitarian organization at the moment of responding to an emergency situation where several lives are at stake. They are also disregarded when planning the camp and evaluating the solutions and suppliers needed, although lately there has been a mind change into evaluating the environmental consequences of long time informal settlements. In our case, the environment takes a more important role and it is considered through measures that will reduce as much as possible the footprint of the design as well as the use of the refugee tent.

In first place, the environment is being protected as a secondary result of the main goals of the design. If a long term solution is achieved, then the generation of garbage and waste from the installation of the refugee tents will be reduced considerably. Also, because of the long life of the materials it is produced of, the footprint of maintenance will be eliminated.

It is important to mention that a common practice by the responsible organizations is to destroy the camp after used, dig a pit and burry all the material and tents used. This damages the surrounding environment, affects the productive properties of the land and brings no future value to the people.

The suppliers that are being considered for the product are high class manufacturers around the world; they consider the environment in their core business strategy and maintain hard control on their productions to reduce the footprint as much as possible. The proposed supplier for the metallic parts of the metallic structure is Swedish Steel AB which maintains a strong environment focus in its operations. (SSAB, 2010)

On site however, it is hard for the design of the tent to consider the environment perspective. Mainly because of the uncertainty of the place is going to be used and the policies the camp will follow. The only way in which the tent can provide to the environment is to ensure that after its use, it can be reused or recycled in a productive manner. In this case, we can ensure that the piping and joints of the tent, while being made of high resistance materials, they will probably be used for several other purposes and it will hardly ever be disposed.

4.3.1 List of Environmental Requirements

Sphere project

- The temporary or permanent settling of the affected population considers the extent of the natural resources available
- Natural resources are managed to meet the ongoing needs of the displaced and host populations
- The production and supply of construction material and the building process minimizes the long-term depletion of natural resources.
- Trees and other vegetation are retained where possible to increase water retention, minimize soil erosion and to provide shade.
- The locations of mass shelters or temporary planned camps are returned to their original condition, unless agreed otherwise, once they are no longer needed for emergency shelter use.

Shelter Centre

- The shelter does not involve materials that are toxic to humans, even when cut or modified for later reuse.
- The shelter does not involve materials that are toxic by burning or burying, and shall not pollute the ground water table or enter the food chain.

UNHCR

49 Shelters shall not involve materials that are toxic to humans, even when cut or modified for later re-use.
50 The environmental impact resulting from the manufacturing or disposal of shelters shall be minimized.
51 Shelters shall not involve materials that are toxic by burning or burying, and shall not pollute the ground water table or enter the food chain.

5. Solutions Development

In this part of the project, I will try to explain the way the development process worked to conclude a final solution. Several different steps were taken depending on the part and the function it performed, all being formed and in consideration with the requirements.

This section is divided the way the different parts were managed. Each part is explained individually but a system development approach is used. At the beginning a study of the relationship between parts is performed to obtain the most efficient way to start working then, based on this order, each part is individually developed.

The purpose is to take the reader through the mental process held to conclude a final solution. As is normal to expect, not all parts took the same amount of time and effort to bring to a close, neither were they equally important. For example, pipes are extremely important, however there is very little to do about their design, it is just a matter of length and bending stress. However joints are also very important but their complicated shape and manufacturing process took some long hours in the design room.

Images are used as much as possible to explain what with words would have been tedious and confusing. All images used are computer generated or properly referenced. The final solution and how it adapts to a real environment use is not found in this section but in the next one "Final Evaluation".

It is important to mention that although all parts were created or developed during this process, the individual path that each part took to its final development was quite different. This is because each part required different areas of knowledge, materials and production methods. Also, even though the entire refugee tent has only one set of requirements, each individual part contributes in different degree to the fulfillment of those requirements, demanding its own customized process. To mention an example, it will became obvious to the reader that pipes respond more to the structure while in the design of joints, manufacturing and transport took a stronger role.

Being the development process of any product an iterative design, this project was no exception. For each part of the tent, an initial design is explained and then after the final evaluation new conclusions are presented. The point of showing this is to guide the reader through the development process as the justification of the final product.

5.1 Description of Initial Solution

When this thesis started, there was already a solution in process. The design consisted on HSS tubes joint together by stamped metal parts. Every corner would include a reinforcement part, also made of stamped sheet metal. All sides were considered to be crossed by plastic tensor braces and the anchoring was planned to be a plate supporting the tubes.

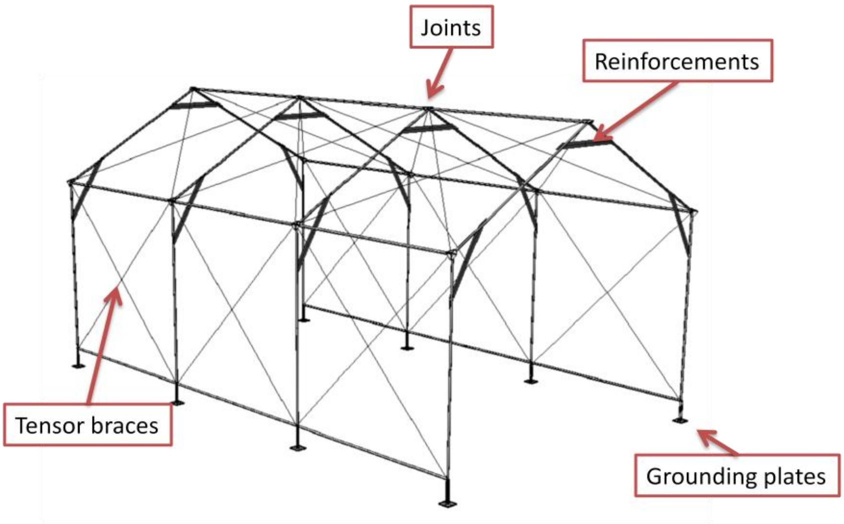


Figure 22 Tent parts

The initial design contained a lot of potential to become a great product. It had few parts and no special tools were required to assemble the whole tent. It could be modular so it could expand and adapt to different uses. Strong coated materials were used to ensure a lifespan for as long as needed. Its volume provided the minimum area space for living set by the humanitarian standards. (Karlsson, 2009)

Some of the opportunity areas the tent had to improve were brought by the same advantages it proposed. The elimination of external tensors would make the assembled tent more comfortable to use but it will compromise the structure stability hence internal side cross braces were needed complicating the assembling and increasing the amount of parts. The sheet metal joints were very fast and cheap to produce but their tolerance control and flexibility altered the whole perception of stability of the tent, therefore a second part was needed. The reinforcements were a simple solution to the stability problem but they would add to complexity and weight.

Based on simple design guidelines the initial direction for the development was drafted. During the next pages an evaluation of different designs for each part is performed based on several analysis and perspectives. Next to the values of the Emergency Housing Project, the main focus is always kept on the end user and the customer. The design development will now be separated into different parts or stages: General geometry, Pipes, Anchors, Joints, Cross braces, Fixing of braces, Corner Reinforcement and Reinforcement configuration.

5.1.1 DSM Matrix

Considering the amount of work required an approach for organizing the work and its sequence was desirable. In this case the Design Structure Matrix seemed like the correct tool to use. The use of DSM was important as the composing parts do not have many different types of relationships between them and the system includes enough different parts to make the use of DSM worth it.

For the use of this methodology, the design is divided into several parts that will be used in the elaboration of the matrix. The parts to be used are: Anchors, structural pipes, joints, corner reinforcements, configuration of assembly, general geometry, cross braces, fixing of braces.

The interdependencies, shown in Figure 23, between them appear to be complex and it is clear to see that iterations would be needed as double dependencies also exist. For example, the reinforcement configuration will change depending on the type of reinforcements to use but at the same time, once a configuration is settled the reinforcements can adapt to it. To support in the organization and display of the information through this method, many different tools can be used. In this case the software ProjectDSM by Project DSM Pty Ltd was used. (Project DSM Pty Ltd, 2009)

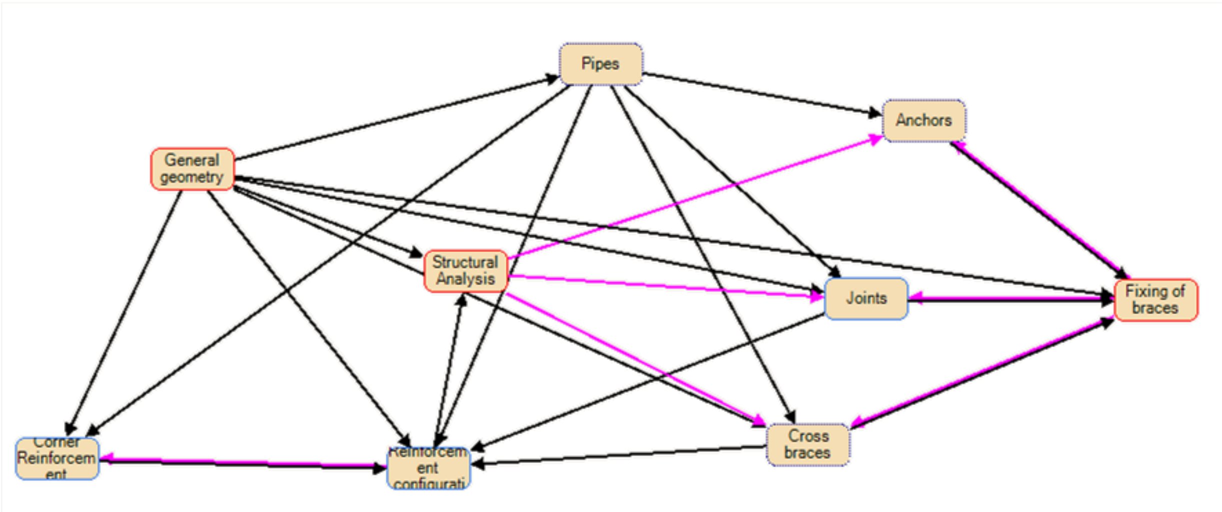


Figure 23 Design relationships

In the relationship map displayed, the black arrows represent the transmission of information in only one direction e.g. the general geometry determines the length the pipes will have, but the pipes will not modify the general geometry as it is stated by the project requirements. The purple arrows represent double relationship like the one explained before between the reinforcements and the configuration.

#	Task	1	2	3	4	5	6	7	8
1	General geometry	●							
2	Pipes	●	●						
3	Anchors		●	●			●		
4	Joints	●	●		●		●		
5	Cross braces	●	●			●	●		
6	Fixing of braces	●		●	●	●	●		
7	Corner Reinforcement	●	●					●	●
8	Reinforcement configuration	●	●		●	●		●	●

Figure 24 DSM

To plan the project based on this information would have resulted tedious and inefficient so the DSM algorithm was run to obtain the most efficient order. The result is shown in Figure 24.

In an optimal case, no red dots should be found over the black dot line. Having a red dot over the black dots line means that iterations will be needed in the future and that assumptions will have to be done in early stages. For example, the red dot that relates Anchors (3) and Fixing of the Braces (6) tells us that the anchors will have to be designed assuming the fixings will have to be somehow tied to them. This assumption may payoff or be wrong but for certain, in the last step, while designing the Fixing of the Braces a review of the type of anchor will have to be performed.

As seen in the dependency matrix, Figure 24, fixing of the braces is the part that will cause most iteration if wrongly designed, however the braces are assumed to be made of a plastic material that can easily be knotted. Therefore, it is safe to believe that the fixing of the braces will consist on a geometry on which any kind of braces can be knotted. This statement will stay correct as long as we do not modify the material or properties of the braces. As seen on the dependency matrix, a change in braces will cause a review of elements 5, 4 and 3.

The pink areas represent codependence. There are many ways to eliminate a codependence like dividing a part into different elements or including one element into another. (Lindemann, 2009) In this case the biggest square will not be resolved for the assumptions explained before. The smaller square at the end represent the correlation between the reinforcement configuration and the corner reinforcements which as explained at the beginning of this section will depend on each other throughout the project.

From the results of the DSM method the following order (considering probable iteration between stages) was proposed to continue the proper design of the different parts:

1. General geometry
2. Pipes
3. Anchors
4. Joints
5. Cross braces
6. Fixing of braces
7. Corner Reinforcement
8. Reinforcement configuration

5.1.2 DSM Extension

Once the project was well advanced, it became obvious that a last step in the development process was missing: a final structural analysis. This structural analysis will come to conclude and reinforce the results obtained in the past. It shall also test assumptions and show hits and misses of the overall development.

It is also to be expected that the results from this final analysis will modify some of the previous work, creating a last iteration. If we include the final analysis and try to predict where the changes shall occur, the updated DSM will change and looks like this.

#	Task	1	2	3	4	5	6	7	8	9
1	General geometry	●								
2	Pipes	●	●							
3	Anchors		●	●			●			●
4	Joints	●	●		●		●			●
5	Cross braces	●	●			●	●			●
6	Fixing of braces	●		●	●	●	●			
7	Corner Reinforcement	●	●					●	●	
8	Reinforcement configuration	●	●		●	●		●	●	
9	Structural Analysis	●							●	●

Figure 25 updated DSM

The most vulnerable parts to change from the results of the last step are those in which forces are more evident: the braces, the joints and the anchors. The excellent performance of these parts makes them critical for the success of the tent, therefore it is expected that they will be optimized to the results obtained.

We also know that together with the pipes, the mentioned parts are constant in all configurations. In the case of the joints for example, although they are all identical, the stresses they sustain for a single load case, are different between each one of them. This will be important to consider at the time of the detailed design which is covered later in this paper.

5.2. General Geometry

According to the DSM, the general geometry was the first issue to work on. There is no surprise in this as most of the elements will change shape according the geometry used. The stresses and forces wind and similar loads are applied on the tent greatly depend on the geometry used. Considering that we opted for a canvas tent as described on the benchmarking, some other details will have to be refined.

A canvas tent would be possible to assemble having all pipes made the same size, reducing cost and complexity while allowing space for modularity, expansion and adaptability. This also gives the property of having an increased height resulting in a more comfortable interior space, factors that directly influence the life of those who live there.

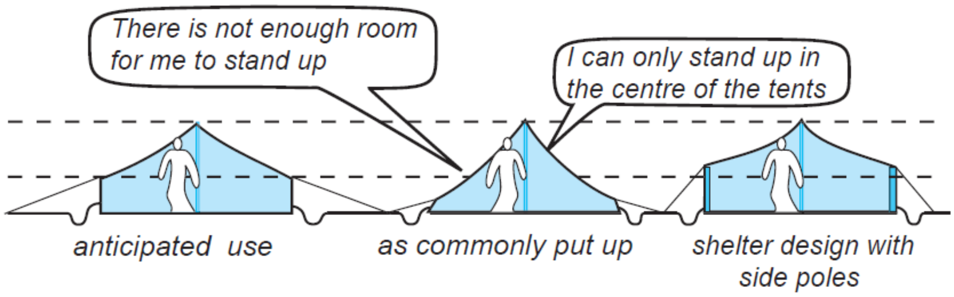
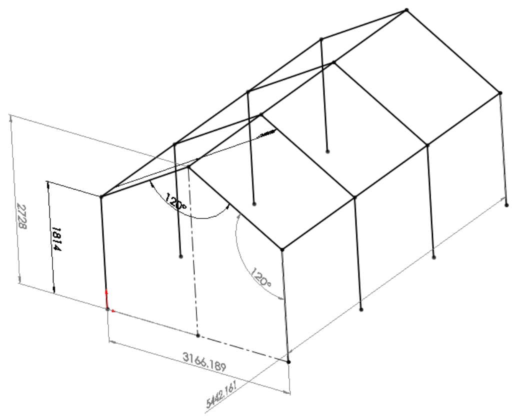


Figure 26 canvas tent sizes (Ashmore, 2004d)

The geometry must also comply with the requirements stated by the NGOs around the world just to be considered as a viable option. To fulfill these requirements, the design enters a tradeoff between space and cost. The bigger the tent, the more expensive it will be due to the use of materials, however the living space will be larger and that would improve the lives of its inhabitants. On the other side, the smaller it is, the cheaper it will be and therefore its attractiveness in the market will increase. The solution to this was to keep the tent in the minimum possible size that complies with the requirements stated by the international organizations.



The geometry needed to be similar to the homes previously owned by the users and also provide concrete cover from the environment. The final geometry changes little from the initially proposed and looks as Figure 27. The only practical difference from the initial design is that the distances between vertexes is 14 mm longer, this due to the geometry of the joints and the space needed to leave between pipes for assembly and manufacturing reasons.

Figure 27 Structural frame dimensions

5.3 Pipes

Pipes had little space for design. It was basically a simple study of the wind forces on the geometry and an approximate weight of the materials to be hanged from them to determine an initial geometry and material properties.

The most important part was the size of them. In order to comply with the requirement of easy to transport and easy to assemble, all pipes should have the same length. There is also the requirement of packaging stated by the UNHCR that states that the maximum length of the package is to be 2 m and that it must fit in a regular pallet. (Ashmore, 2004a)

Pipes are also important as most of the weight of the tent depends on them. They are the most heavy and most expensive element in the tent. In order to reduce the cost of transport and the weight, it became obvious that a high strength material with very low weight would be the best choice. With the purpose of obtaining such material, we visited the city of Borlänge in the middle of Sweden where SSAB is located.

The proposed material is a high strength steel that can be galvanized for weather protection. With this we can control the heavy weight tents usually have and at the same time increase its durability, resistance and future development into a home. After doing the final simulation, we can see that the pipes comply with the mechanical requirements.

5.4 Anchor Evaluation

Once the structure for the tent was defined, different anchoring systems had to be evaluated. The requirements for the anchoring are stated in section "4.2.1 Anchor Desires" and they will serve for evaluating the different solutions. An initial scan on the internet was performed to obtain the different types of anchoring systems that are used on similar products. Different catalogues were consulted, both from the commercial solutions and the official UNHCR and IFRC manuals. (Ashmore, 2004b)

Out of the many commercial solutions that are available on the market, those that provide the best potential to cover the requirements are displayed in the Appendix G. Considering these basic designs, the Kesselring method was applied to evaluate as objectively as possible each option based on the desires previously stated.

Table 4 Anchor Kesselring

	repositioning	Installing	price	weight	terrain adaptable	stress resistance	Availability in market	Total
Rachet Tite	1	5	2	5	5	5	2	25
Shelter Auger	5	3	4	3	4	5	5	29
Shelter Spike	4	5	3	3	4	5	2	26
T or V pegs	5	5	4	4	3	4	5	30
round pegs	4	4	5	5	1	1	5	25
Hogan auger spike	5	2	1	3	4	4	1	20

From the previous table we can observe that T or V pegs together with the Shelter Auger spikes are the best solutions for anchoring. However the vertical loads that pull the tent out of the ground level are better supported in the case of the Shelter Auger and that is why it was considered as a better option.

The design of the tent also requires second modifications on the anchoring system. Not only it has to keep the tent in its position but it must work as a mechanical part with the tent. It should also be the support for the lateral braces; therefore second modifications are needed for the anchoring system.

A brainstorm was conducted that resulted with the solution of incorporating slight modifications to the end of the anchor so it would fasten the pipes and the braces without adding extra parts. The strange "T" shape that is found in the top serves the purpose of positioning the pipe in its right position and to provide a certain degree of vertical resistance to rotation. The two lateral sides serve as support for the pipe so it won't stick inside earth and at the same time provide space for the braces to be tightened to. It is foreseen that pipes can be used as tools for positioning the anchors into the ground, positioning one on the sides and one in the top. This way the force applied by the constructors will increase dramatically.

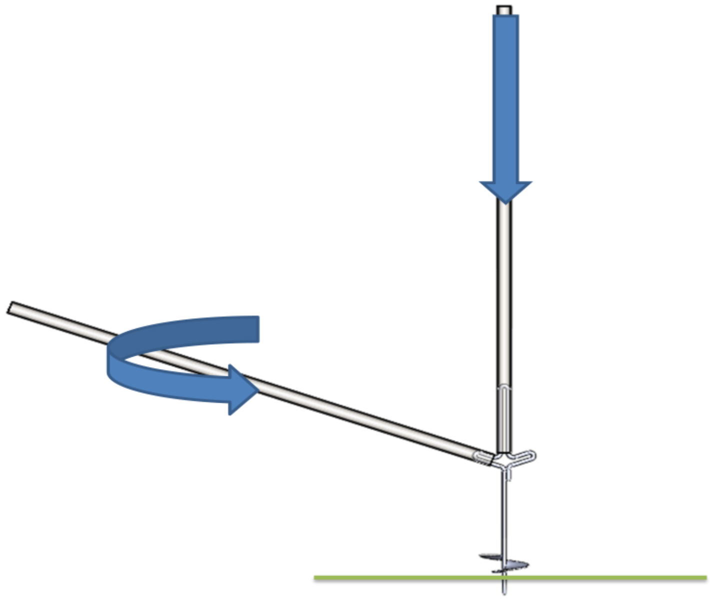


Figure 28Auger Anchor installation

After obtaining the results from the software simulations for different load cases, an interesting effect became evident. As it is very hard to estimate the resistance the anchors will provide for the rotation of the pipes, two different configurations were run. One configuration will assume that the pipes are totally fixed in every translation and rotation; the other will only assume the pipes get fixed to the ground position but they are free to rotate in all directions. The results can be seen in the following images:

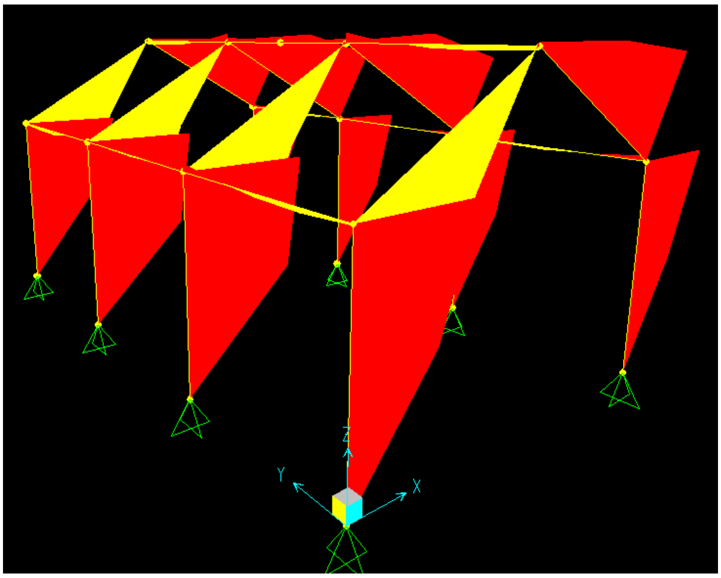


Figure 29 Stress simulation with free rotation of pipes at anchor

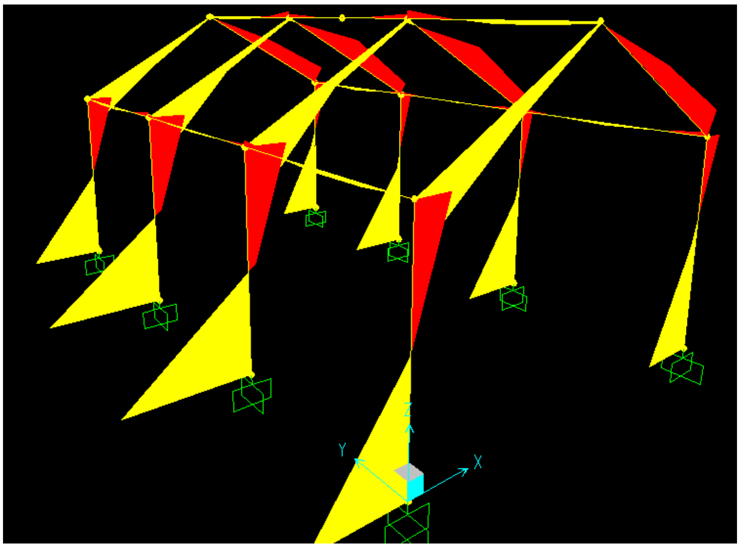


Figure 30 Stress simulation with pipe rotation limited by anchors

The two results show the evident relationship between the resistance anchors provide to rotation and the moment the joints will have to withstand. Due to the great variation ground conditions might have between different camps around the world, we cannot predict in what place between these two results the actual built tent will be.

Considering the results obtained, different actions must be taken. On the first place, it is clear that the joints will have to be designed and tested for the worst case scenario (free rotation); The anchors will need a design that will allow to reduce the rotation of the pipes as much as possible and finally, a strong recommendation to the installer to avoid rotation of the pipes after the assembly.

These final requirements together with the need of finding a specialized manufacturer lead to the design of a different kind of anchor, still based on the original Auger anchor but with a pipe instead of the bent rod. On one side it eases the manufacturing of it; however it complicates its installation on field. More details about this change are found in section 6.2 Manufacturing.

5.5 Joints

The joints represented an extremely complex system to solve. They must be addressed in several diverse fields and must comply with very different kinds of requirements. At first sight they are a structural part. Most of the stresses the tent will support transmit through the rest of the parts by the joints. They should also be easy to manufacture, we want to be able to produce as many and as fast as possible so they require a simple geometry easy enough to produce in just a few steps. On another plane, they should be easy to understand so that people can assemble them quickly and without any special instructions. At last, a detail that increased their complexity is the need to keep them in a reduced volume while packed for the interest of the NGOs that store them and provide them.

All the previous challenges were faced one by one until a very nice final design was achieved. During the following pages, a resumed outline of the development process and the calculations to it are explained.

At the moment the thesis started, the project had several prototypes for the joint already made. The design was very efficient as in just a few stamping operations the 3D joint could be made out of a flat sheet metal. If done with the right material it could easily support the loads it was subject to.

Figure 31 pictures of original joint

The joint however, lacked a few details to fulfill all the stated requirements. As a first approach, fillets were introduced in the corners of the cuts to reduce the stress concentrations on the part as well as to improve the bending process.

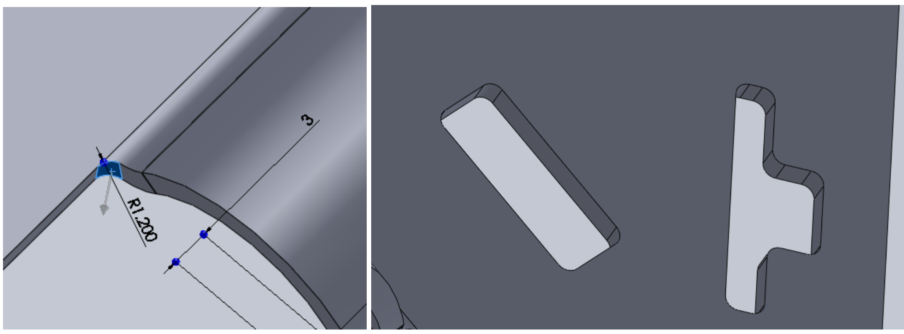


Figure 32 introduction of fillets in joint

The general geometry was also in need of a few modifications. The bending radius needed to be adjusted to the thickness of the material, plus it was needed for controlling the tolerance of the manufacture.

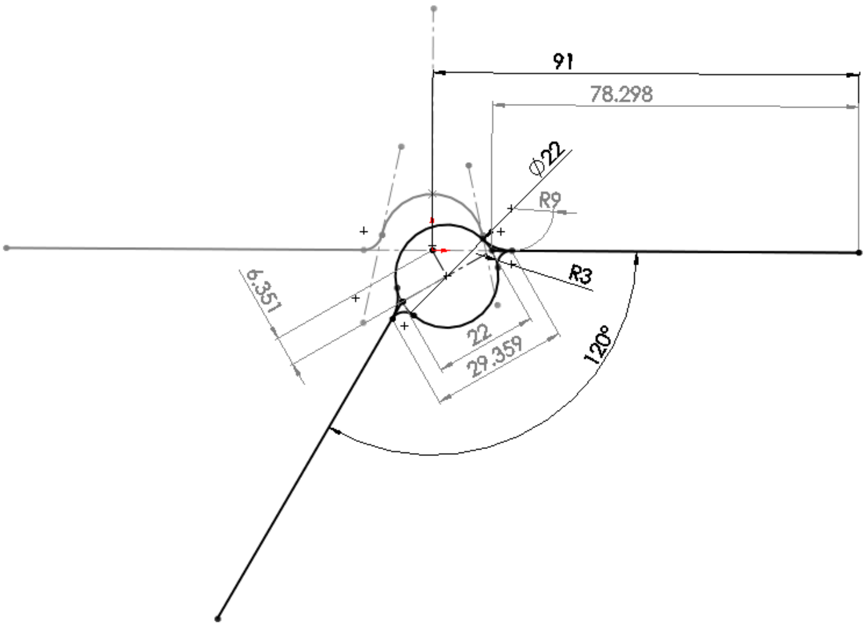


Figure 33 Neutral line bending Sketch

As a first approach, the center of bending stopped being on the center of the pipe entrance, in this way we could have the same length of arc in the top and in the bottom of the joint thus reducing stresses that were creating later deformations on the final product. In the image we can see the neutral line of the joint, representing the midline of the sheet metal and how it is bent.

Another slight adjustment was in the bending radius of the 120 degree line. As top and bottom curves have different geometries and arc lengths it was important to be able to start the cut in the same place.

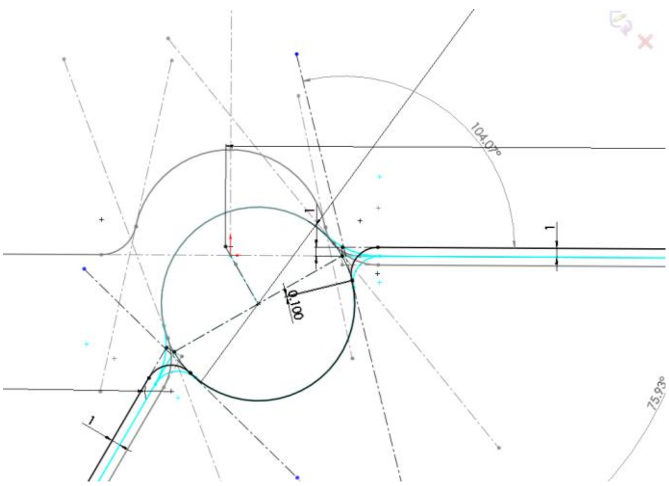


Figure 34 bending cuts

With this, we can resolve the problem of having oval circles resulting in a better tolerance control of the geometry which at the end, translates as a smoother assembly for the final user.

It also improves robustness as variations in bending and deformations the part might get caused by poor handling will not prevent the part from working on the field.

The last feature to modify was the capacity to store and pack them in the minimum volume possible. In a standard tent, twelve joints are required provided that none are used for extensions or reinforcements. They represent a very large volume if stored independently. A normal joint at this moment had a volume of: 172 x 162 x 50 mm

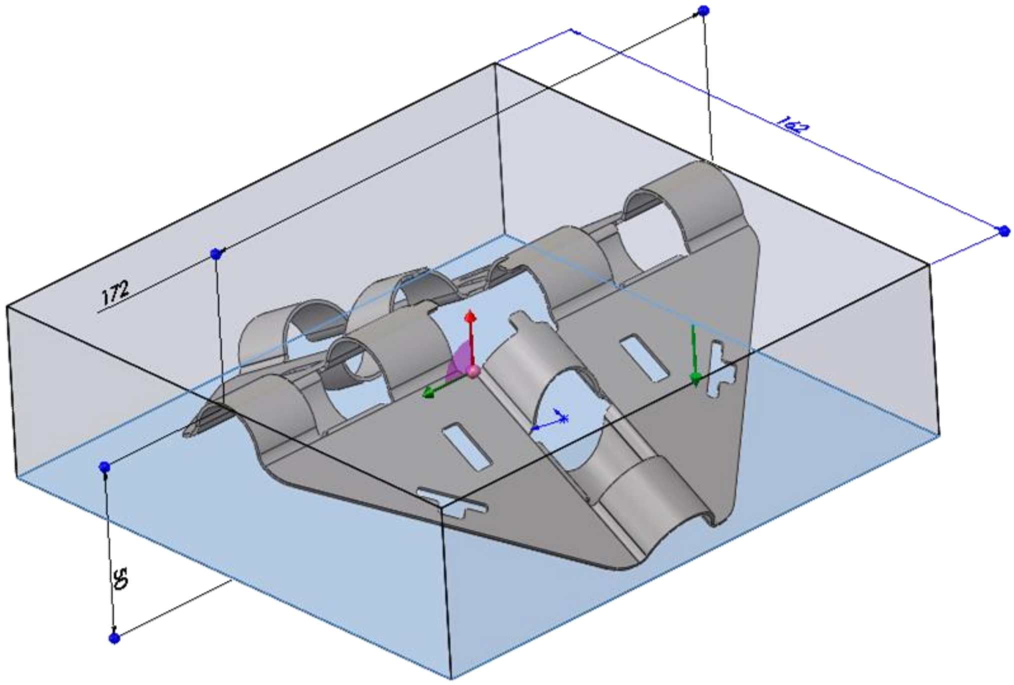


Figure 35 Joint packing volume

This volume was not acceptable, plus having all the joints free would make it easier for them to get lost. For this reason, a way for stacking them was introduced. An elliptical cut in the plane would result in a vertical diagonal cut over the bent parts letting them fit between themselves, creating one single package and making transport and storing a simple task. A lateral advantage of this arrangement is also that while being in a package, the parts get protected from rough handling thus improving their performance to the final users.

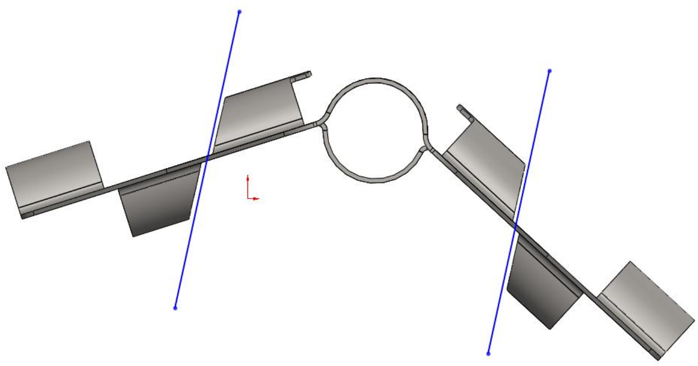


Figure 36 Stacked joints

Figure 37 Lateral cut view

After defining a final geometry, several simulation tests had to be performed on the part. Using the information learned from the stress simulation, we must consider the mentioned case in which the anchors are not able to prevent the pipes from rotating while at the same time there are no reinforcements in place. This is the considered worst case scenario. The results were not optimistic. At this condition, the efforts the joint will sustain are far over the capacity of the material hence in strong winds the joints would not be able to keep the structure stable. Nevertheless, with proper anchoring and reinforcements in place, the moments exerted over the part, get reduced in such a way that it is safe to assume that it will easily sustain the effects of strong winds.

In the two images we can see the factor of safety per region of the part on two different scenarios.

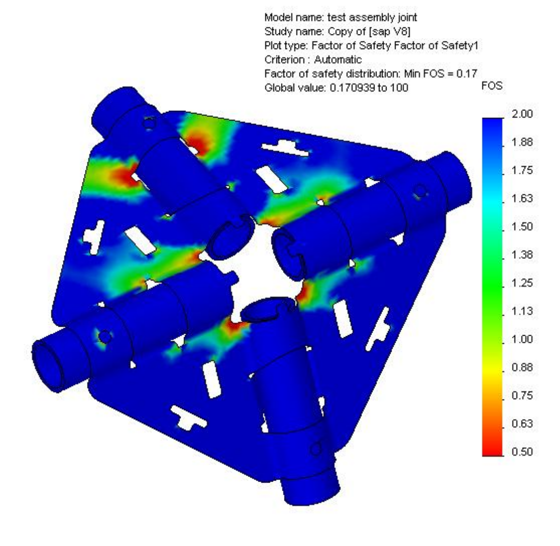
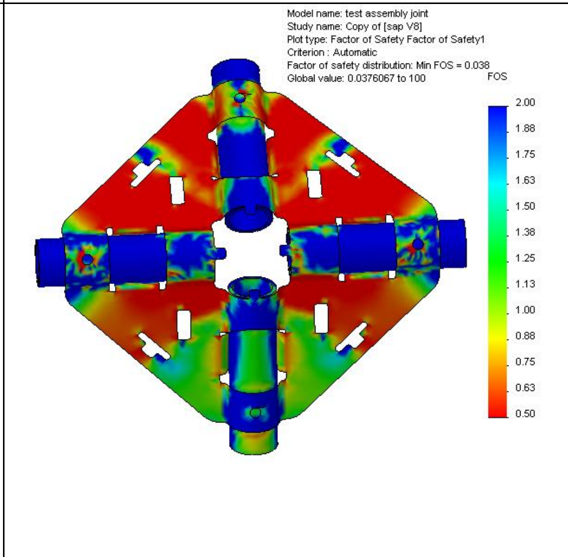
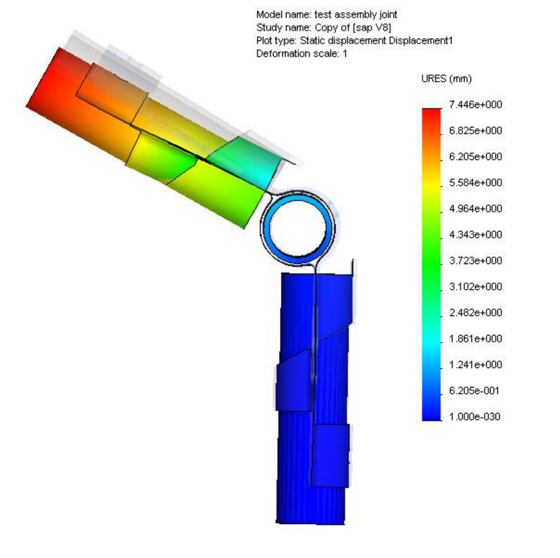
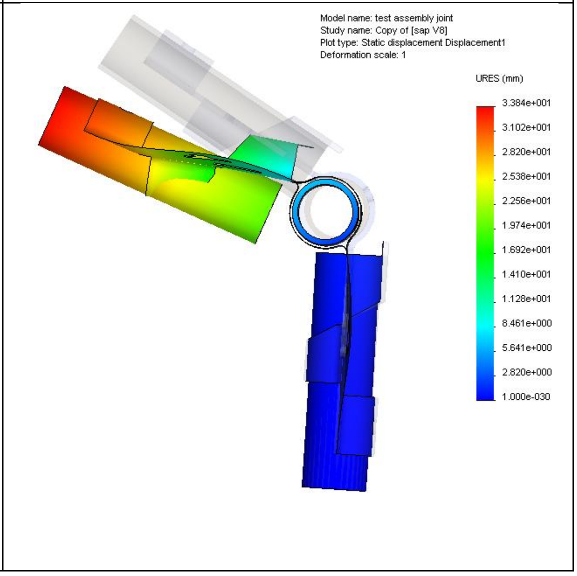
<table>
<tr><td></td><td>Case 19 with reinforcements</td><td>Case 1 no reinforcements</td></tr>
<tr><td>Factor of Safety</td><td>
</td><td>
</td></tr>
<tr><td>Displacement</td><td>
</td><td>
</td></tr>
</table>

Figure 38 Comparison of Factor of Safety and Displacement for joint

A last modification proposed to the final design was the introduction of gussets that could increase the bending resistance especially in the direction that is more vulnerable to stresses. It is expected, as shown in Figure 39 that the gussets help considerably to the mechanical behavior of the part, however the work for testing and simulating the idea becomes quite complex. Also prototyping cannot happen as easy as with the previous designs due to the need of expensive tooling.

All this considered, the increased amount of work for prototyping, simulating and manufacturing the part would take much more time than the one assigned for the project, hence it is left for future work. It is also very important to mention that the final design used for the first batch of prototypes is not my proposal, however it was well considered. The final differences are found in the Appendix F

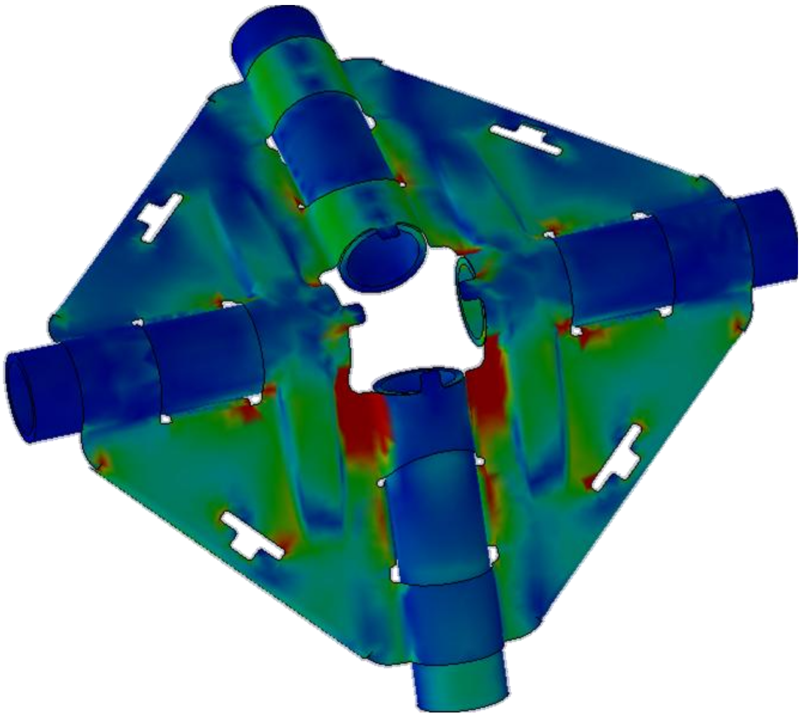


Figure 39 Joint with gussets

5.6 Cross Braces

Cross braces are an important element in the reinforcement of structures. They are specially used to reinforce light weight structures in an efficient manner and they can be found in many different projects ranging from buildings, bridges and camping tents. Because of their strong advantages, cross bracing, was proposed to reinforce the structure since the beginning of the project; however the manner in which this was to happen evolved during the project.

Figure 40 Cross braces

When studying about similar solutions in the market I realized that other projects came to the same conclusion. Such is the case in the study performed by the Housing and Hazards group through Shelter Centre, where a clear increment of the structures stability was reported by the simple act of incorporating cross bracing in the walls. (Anwar, 1999) What is most interesting about this series of articles is the incorporation of engineering principles in a non engineered construction.

The uncertainty of the structural integrity of these houses, made with local very different materials is compensated by the use of well known and proven engineering principles. This approach is repeated in the findings of Lewis and Chisholm who evaluated some modifications in the local constructions to increase their safety when dealing with cyclones, a common problem in the region of Bangladesh. (Chisholm & Lewis, 1999)

Taking the knowledge from previous experiences and articles, it became obvious that cross bracings were more efficient when used on the side walls than in the roof, and also when they are used in “X” pairs between individual structural members, especially in the center of the geometry. This is a conclusion that was restated after my own analysis, better explained in the following section 4.9.1 “DOE for structural members” of this thesis.

The material to use had to be as light as possible and very cheap as large amounts of it were needed for each tent. Bracings should also be replaceable, an issue described better in the next section. Also, in accordance to the overall requirements its volume while packed should be minimized plus they should be available easily from manufacturers around the globe.

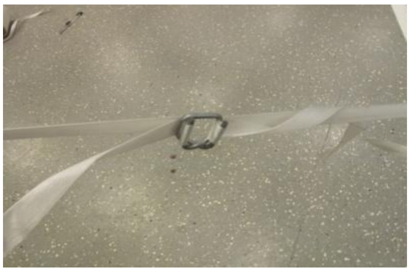


Figure 41 Brace tensor

At the end, a common stripe of plastic brace was chosen, this has very high strength and are available everywhere, plus they adapt very easily to the tent and in case of needed, they can be used for very different purposes on site. They can also be replaced with some similar material locally available if needed.

The material however posted a problem in the future of the tent. Plastic materials like this one are known to yield after some time, therefore require readjustment and constant tightening of the structure, mainly after some time has passed of the first installation. Other elements were evaluated to try to avoid this like metallic cable but then they would be considerably more expensive and heavy plus hard to install and they would demand special endings.

5.7 Fixing of Braces

Once the type of material that ought to be used for braces was defined, its attachment to the rest of the structure was elaborated. The material was very flexible and easy to adjust to complicated geometries so many different options could be considered. At the end, the solution was to tie them to the joint and to the anchor.

The problem however is its assembly time. After a few exercises, it became evident that installing them is very time consuming and their success relies greatly in the ability the user has to do the proper knots. To resolve these problems, other solutions were evaluated and compared with market products. Normally, specialized hooks are developed for each kind of tent but this increases dramatically the costs and reduces the capacity to be replaced with local materials.

The decision to remain tying the braces to joints and anchors was in accordance to the requirements, although if the appearance of the final product was affected. Nevertheless, the manufacturers of such bands produce very low cost tensors. With this included, one could tie both ends and apply tension in the center to tighten them. This reduces incredibly the maintenance time and complexity. An example of such can be seen in Figure 41.

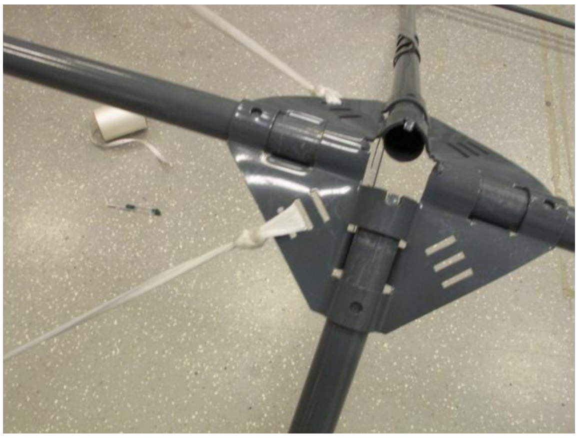


Figure 42 Joint with cross braces

5.8 Corner Reinforcements

The structure made by the pipes and the joints alone is too weak. It feels completely unstable and there are high probabilities it would fail. A solution for this could be modifying the joints, making them more robust and hard, however this would result in a very heavy part, hard to package and very expensive to produce. In exchange for that, the use of reinforcements at the corners could provide the sufficient stability required for a safe tent.

The use of reinforcements also brings the possibility to place them only when needed the most, saving in cost, weight and volume as the design becomes as most efficient as possible. It is clear that several issues have to be considered to make the best solution, however the most important factor is the improvement of the whole structure stability while increasing a minimum of weight and cost. The distribution of reinforcements together with its analysis is shown in section 4.9 “Reinforcement Configuration”

Once the need of reinforcements was agreed on, two different proposals were considered to take the task. One, a stamped sheet metal bent to hold the pipes made in a very similar fashion to the joints. The second one is two modified joints that will hold an extra pipe in the center. To make the decision of the best one to use, a structural analysis was performed and the results were compared to the cost and weight increment per stability acquired. The details of this study can be found in the following section.

Figure 43 Reinforcement Types

Table 5 Reinforcement type properties

Reinforcement types		
	Stamped	Pipe
Weight kg	0.4 kg	1.15 kg
Cost SEK	6.4	18.9

5.9 Reinforcement Configuration

Having the possible reinforcements designed is not enough. One could think that they could be placed in every corner possible and that the tent would be very strong, however this would add a lot to weight and cost. For this reason the most efficient combination of reinforcements was investigated.

5.9.1 Design of Experiments for Structural Members

The method of design of experiments was used to obtain the most optimal configuration of reinforcements. The parts were considered the input values and the level their presence or not in the structure. Over 50 runs were made and a final 6 configurations were presented as the best ones as shown in Figure 44. To see the detailed procedure of the mentioned process Appendix H can be consulted.

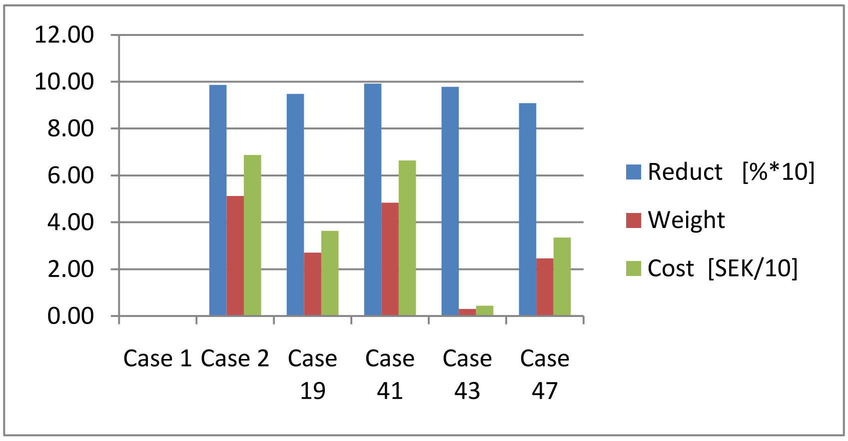


Figure 44 Top configurations and reference

After the theoretical results from the analytical experiment were obtained, a physical test was performed to evaluate the validity of these results. The results obtained as seen in Appendix I were quite optimistic and a final decision was made for case 19.

19

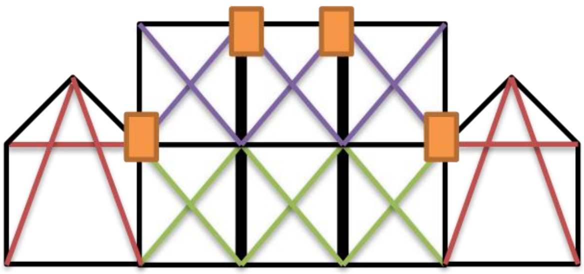


Figure 45 Case 19, recommended reinforcement configuration

6. Detailed Design and Evaluation

Once a design decision was made for every part of the tent plus the reinforcement configurations, a final design of the whole system was performed. In this chapter, the results from the final iteration of design are presented. The evaluation on manufacturing, assembly, usage, etc. to ensure that the project complies with the initial target requirements is explained.

The first step was a full structural analysis that served as a security test to ensure that the parts are able to support the loads everyday use and weather conditions will exert on the tent. For this analysis, basic forces were applied representing the wind, snow and approximate roof loads. As it can be seen in Appendix E, the initial idea that the metal frame could be able to support all loads without any corner reinforcement or cross bracing was dismissed as the stresses are quite elevated. However, after introducing the proper configuration, there could be seen an overall increase in the performance and safety of the tent.

A full manufacturing analysis is very important for ensuring that the tent complies with the stakeholders' requirements and the production capacity of the manufacturers. In this chapter, final slight modifications to the tent are done to ensure that its production capacity will not affect its performance.

Considering the tents have to be raised as fast as possible and that people must learn how to assemble them on site with little or no instruction, an assembly test to evaluate the practicality of the design is of the outmost importance. In the section, Assembly Analysis, different scenarios of misassembles and their consequences are evaluated to ensure that no damage is done on the parts if misused.

At the end of the evaluation, a refinement and detailed design of the parts is presented. This is where the thesis finishes and a final prototype is ready for onsite testing.

6.1 Structural Analysis

Based on the requirements stated by the NGOs and The Shelter Center, explained in the previous section "Requirements", a final analysis was performed. It tries to include all the information generated to the moment; weather, reinforcement configuration, proprieties of the most important elements, etc. It aims to provide feedback for the job done to perform a last iteration doing the detailed design.

Because of the nature of the tent working as a temporary settlement, the Euro code was used to calculate the wind and snow pressures on the overall structure. Conservative values are used however it is considered that the structure varies considerably from the buildings the code was meant to be for.

All the analyses were done with the same software as the contribution analysis performed in the design of experiments evaluation, SAP2000. This software is widely used in professional large scale project applications. However, to simplify the analysis some factors were purposely disregarded for the simulation and several assumptions were made as shown by the following list.

- All parts are assumed to have perfect materials
- No dimensional variation between parts
- All cross braces are tied at the same initial tension
- Anchors are ideal and do not displace in any direction
- Anchors only fix translation in every direction
- Anchors do not prevent rotation in any direction
- The covering fabric does not influence in any way to the structural integrity
- The wind forces on the cover pass directly to the structure.

It is important to mention the valuable help received by Gijsbers from the Shelter Research Group at the Eindhoven University of Technology. The input data used in the analysis was obtained from the report delivered by him. (Gijsbers & Cox , 2011)

The results shown aim to conclude in a final product. This is the last step of analysis over the whole tent. Later with the results of this analysis, optimization shall be done on the individual members of the structure.

As stated in the requirements, this is the most important test to pass. It will determine the security of the tent to be used as a safe place to be habituated by those in need. It can also be seen, through the stage gate approach, as a go/kill decision. (Cooper & Edgett, 2009) Without passing this test, the overall design will need strong modifications.

6.1.1. Determination of Loads

The amount of information and standards for the design of a light weight structure are not as well documented as those for hard buildings. Nevertheless, with basic concepts of fluid dynamics, some numbers were derivate from the information on wind velocity and the geometry of the tent.

Two main sources worked as reference for this analysis: the thesis of van Kemenade (van Kemenade, 2007) and a preliminary analysis made by the tarpaulin manufacturers. From these two different perspectives, the information required for this project was applied.

The First reference, the work done by Kemenade, presents a very similar work to this thesis. Although the final outcome of his work is quite different, his approach to solve the mechanical forces exerted by the wind on the structure is very useful in the context of this work. What makes this method a preferred one is that he simplifies the use of the Dutch standard over the structure of the tent. Applying this into my own work would result in the analysis shown in the Appendix E, and the final results look like this:

Table 6 Loads on frame based on Dutch standard

Loads on structure [kN]	
Load A	3.50
Wind A	5.44
Wind B	-2.72
Wind C	-2.72
Wind D	-2.04

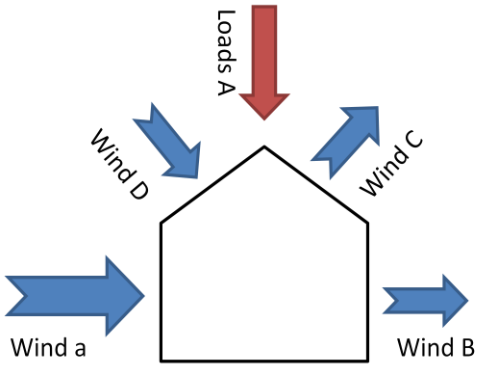


Figure 46 Direction of loads

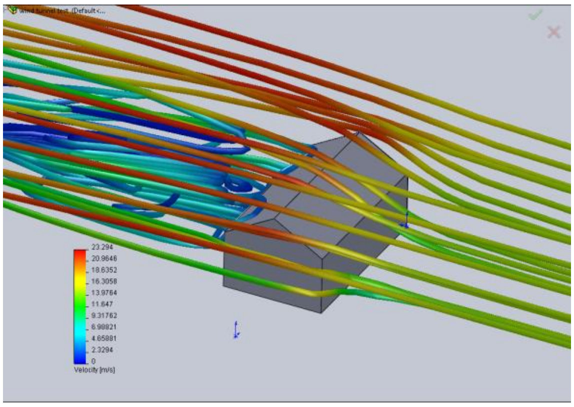


Figure 47 Representation of wind currents

The second analysis I used as a reference, was an evaluation done by the technical university of Eidenhoven (Gijsbers & Cox , 2011)in which they analyze the forces a fabric covering will have to support considering similar conditions of wind load over the structure.

The results from this analysis are different from the first ones presented in the chapter. We can assume that it is because they use different standards however they have final values in the same range so we can assume that after the security factor, both results are covered.

The way this study worked was simulating the effects of a plastic or fabric covering over the tent while the wind blow perpendicular to it. The purpose was to analyze whether the cover material would be able to support the wind tension. However it is important to consider that the forces applied on such a cover change considerably depending on the position and size of openings. (Chisholm & Lewis, 1999)

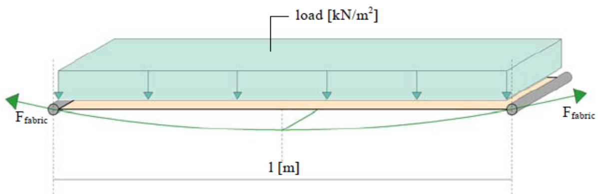


Figure 48 load on fabric

The results from this approach were not concluding as the purpose was not to determine the effects on the overall tent but only in the parts where the cover would have larges stresses. However they are very useful to compare and gain an idea of the range of forces that such a structure would need to deal with.

Dynamic pressure of wind @ 31 m/s = 1.3213 kN/m^2

Table 7 Dynamic pressure of wind at 31 m/s		
	Wind from Front	Wind from Side
Pressure on side 1	-2.1144	
Pressure on side 2		1.5856
Pressure on front 1	1.5856	
Pressure on front 2		-2.1144
Pressure on roof	-2.3784	-2.3784
Snow load on roof	0.288	0.288
• **All units are in kN/m^2**		

With all this considered, we can appreciate that most pressures on the walls is under 2.5 kN/m2 and that only the front wall with high winds will take larger values. From these two approaches, the largest values on each part of the tent were considered for the design.

With this information, the next step was to corroborate that all parts in the tent would be able to perform according to the requirements. In the next section, the simulations of how this is corroborated are explained.

6.1.2 Software Simulation

With the information of the main loads it is now possible to simulate the reactions different parts of the tent will need to resist. There are three main parts of concern that are needed for the rest of the development process: The joint, the pipes and the anchors. I wanted to be sure that both pipes and joints would be able to support the stresses of everyday use without failing. On the other hand, the forces on the anchors need to be studied to have certainty that they will be able to maintain their position to keep the tent in place even under strong winds.

The analysis assumes the same conditions that were explained in section "DOE for structural members" and it is done with the same software. The difference with this study however is in its purpose, input values and intended result.

The purpose is now to verify the capacity each individual part will need to deliver as expected. To ensure that the tent is safe the output value of the simulation will be compared to the mechanical properties of each element. The input values are those obtained during the previous chapter. As mentioned before, this study intends to verify the design, after the analysis it is not expected that major changes ought to be performed.

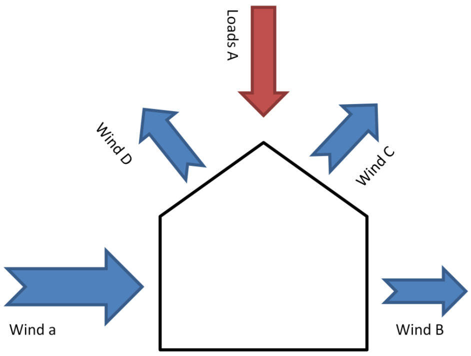
To simplify the task, only two configurations would be simulated. The Reinforcement configuration that applies in this case is number 19, plus the tent without any reinforcements. This is done with the purpose to verify the importance of reinforcements under a critical load scenario and to be able to create a set of recommendations of use for the final user.

The first part of the analysis was the introduction of the parts information. The profile of the pipes is the most important element to define. For simplification purposes, the joints are considered rigid between pipes and the anchors are considered constrained in all directions. The basic model used is almost the same model of section 4.9. The only difference relies on the forces applied on the elements.

The next step is to obtain the loads to be applied on the model. Because the software works with distributed forces, the input is transformed from a punctual force to the distributed force each member of the structure will support. The results for this procedure are as follows. We can see how the internal elements loads (Fi) are twice the value of the external elements (Fo); an expected outcome for this type of analysis as the inner members always support bigger loads.

Table 8 Distribution of forces over metallic structure

Distribution of forces over metallic structure			
Distributed Forces = Load / length			
Wall A		Roof C	
Fi	1.008	Fi	-0.504
Fo	0.504	Fo	-0.252
Wall B		Roof D	
Fi	-0.504	Fi	-0.378
Fo	-0.252	Fo	-0.189
Roof A		* All data in [kN/m]	
Fi	0.093		
Fo	0.130		



After this process, the final model in the program would look like this:

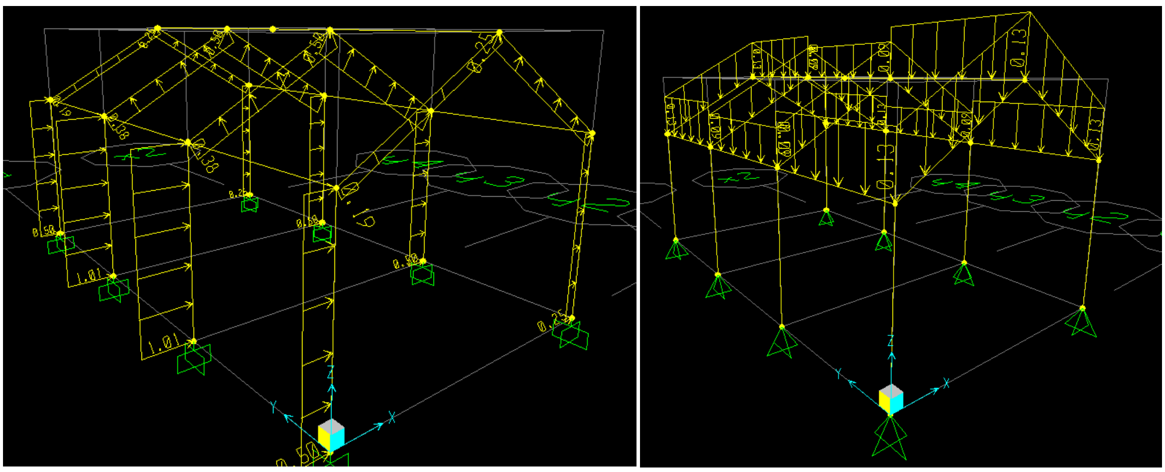


Figure 49 Simulation model, input forces

The output moment on each element in the relative direction of each pipe would be as seen in Figure 29 and Figure 30. It is important to notice how different the forces are depending on the role of the anchors.

The next step was to verify the pipes as a proper structural member. From the software we can also retrieve the information of the forces that apply on each individual member. The pipes which receive the largest amount of forces on both cases are the center ones found in the wall at which the wind hits.

For the case of full restrain, the pipe would be subject to the following load distribution of the image on the left. For the case of no restrain the load distribution can be seen on the right image

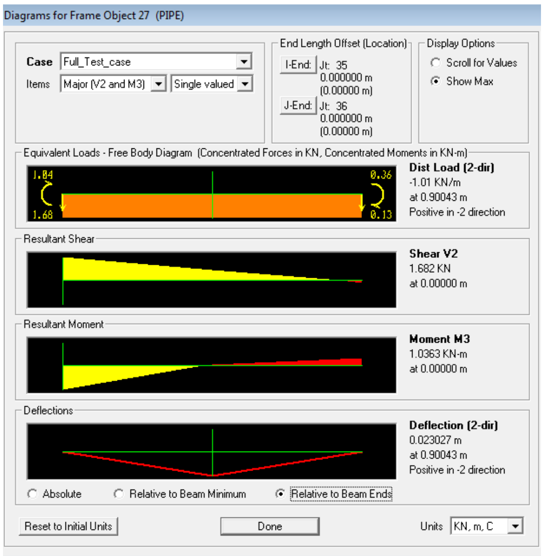


Figure 51 pipe stresses case 0 no rotation

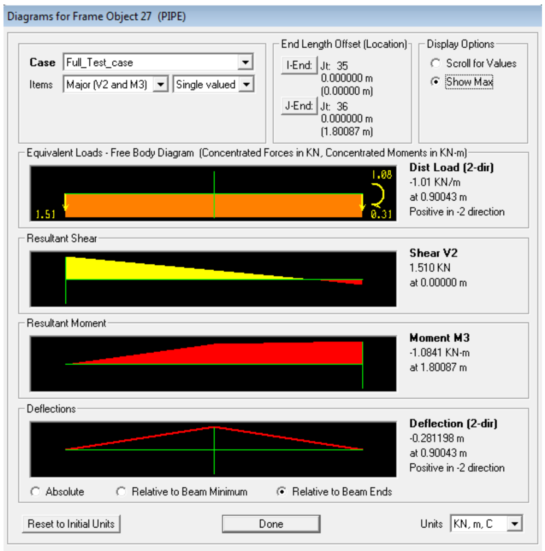


Figure 50 Pipe stresses case 0 full rotation

The images are showing us the load distribution with the maximum values noted to the right. With this information it is only necessary to compare to those of the pipe properties to ensure its reliability and safety factor. This comparison was performed in section 4.3 Pipes.

Considering that all parts are not able to support the loads in extreme conditions, an evaluation of these results while having some reinforcements was interesting to see to assess the importance of having reinforcements in the structure. For this matter, configuration case 19 was evaluated. For Case 19, the moment diagram looks like Figure 52:

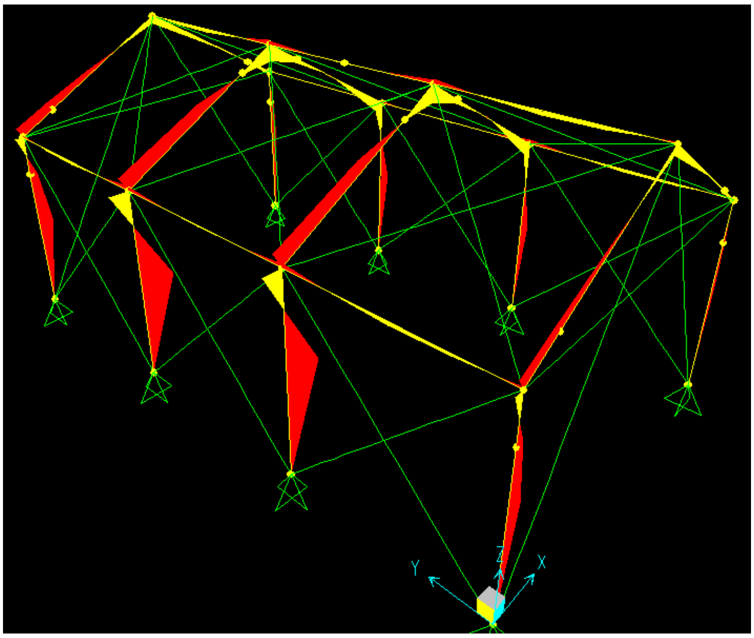


Figure 52 Case 19 moment distribution full rotation anchors

The introduction of the reinforcements clearly improved the mechanical conditions of the tent, reducing the stress in pipes and joints.

When including the totally restrained anchors in case 19 and running the same simulation, we can also see how the efforts on the joints and on most of the members got reduced considerably. In the next pages the forces applied on the joints and their capacity to bear them will be analyzed in a finite element analysis software.

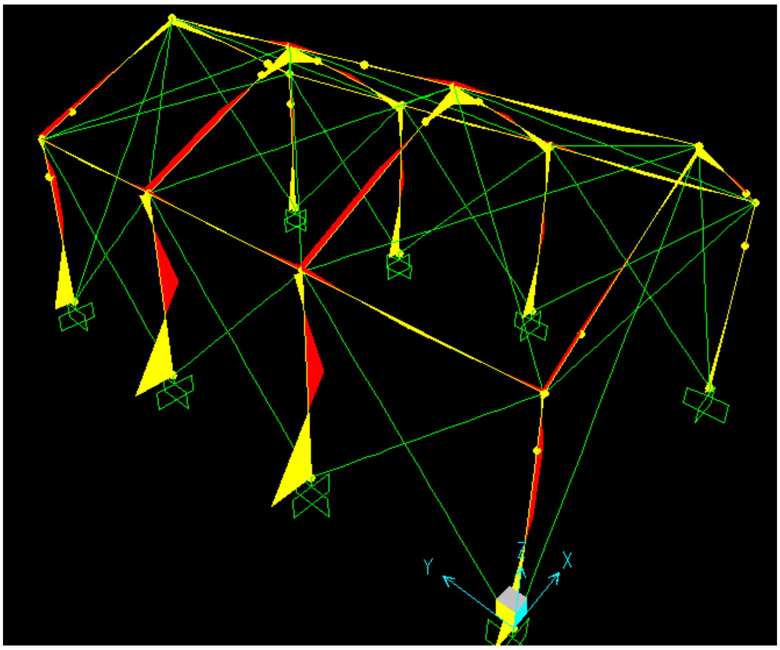


Figure 53 Case 19 Moment distribution, fully constrained anchors

Joints

The information obtained from this study also works for trialing the joints. Now that we know that different load conditions drastically change between themselves depending on the parameters explained, we used the values obtained in the previous analysis to create a load case for the joint.

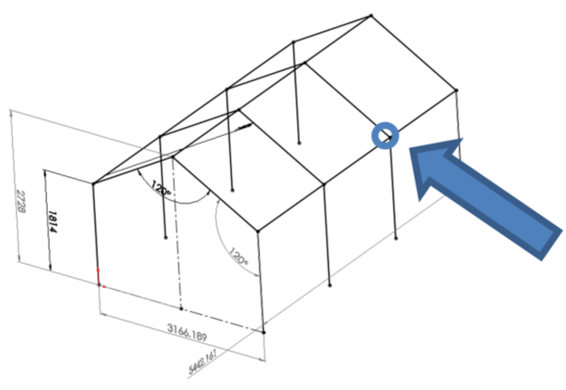


Figure 54 Joint 36

As simulating every joint in every case would be a rather pointless activity, a sample joint in one of the most stressful positions is chosen. In this case, Joint 36 (as named by the simulation software) will be the testing joint. This joint is in the center of the tent in the wall that receives most of the loads, hence is the most stressed.

The analytical values, for joint number 36 in the initial configuration without any kind of reinforcements and without rotation constrain at the anchors is:

Table 9 Joint 36 case 0 forces full rotation anchors

Frame	Joint	F1	F2	F3	M1	M2	M3
		KN	**KN**	**KN**	**KN-m**	**KN-m**	**KN-m**
27	36	-0.306	-0.002	0.697	-0.003	-1.084	0
29	36	0.166	-0.114	-0.939	0.042	1.105	-0.095
40	36	0	0.259	0.084	0.022	0	-0.042
41	36	0.139	-0.143	0.158	-0.061	-0.021	0.137

The analytical value for joint number 36 in the same case but when the anchors provide full constrain in all directions.

Table 10 Joint 36 case 0 forces, fully constrained anchors

Frame	Joint	F1	F2	F3	M1	M2	M3
		KN	**KN**	**KN**	**KN-m**	**KN-m**	**KN-m**
27	36	-0.133	0	0.275	0	-0.358	-0.009
29	36	0.041	-0.069	-0.501	0.025	0.365	-0.057
40	36	0	0.162	0.084	0.025	0	-0.023
41	36	0.092	-0.093	0.142	-0.050	-0.007	0.089

As it is evident, the values registered on the same joint are considerably smaller when the anchors are providing sufficient restrain to the pipes. This emphasizes the importance of having a very well anchored tent.

In the same fashion, when applying the reinforcement configuration 19 to the blank tent, we can easily appreciate the reduction of stresses in the parts. Also, the effect of having fully constrained anchors became evident.

Table 11 Joint 36, case 19, full rotation anchors

Frame	Joint	F1	F2	F3	M1	M2	M3
		KN	KN	KN	KN-m	KN-m	KN-m
27	36	-1.008	0	-1.040	0.006	0.181	0
29	36	1.077	0	0.513	0.003	-0.155	-0.007
40	36	0	1.616	0.092	0.032	0	0
41	36	0.002	-1.561	0.137	-0.041	-0.025	0.006

Table 12 Joint 36, case 19, fully constrained anchors

Frame	Joint	F1	F2	F3	M1	M2	M3
		KN	KN	KN	KN-m	KN-m	KN-m
27	36	-0.73	0.006	-0.745	0.007	0.077	0
29	36	0.809	-0.008	0.288	0.002	-0.061	-0.005
40	36	0	1.26	0.092	0.031	0	0
41	36	0.001	-1.194	0.135	-0.041	-0.016	0.004

From all the parts in the tent, the two most critical parts are the anchors and the joints. This is stated based on the capacity to deliver their purpose and comply with the initial requirements of the whole project. The joints are responsible for resisting most of the stresses the tent receives and still stay light, manufacturable and easy to package in small spaces, this lead to an easy to make shape but that is not capable of bearing large amounts of stress. As a result of this design, the need on anchors and reinforcements to deliver proper results increased.

To explain the differences in a clearer way, Table 13, shows a comparative table between cases. The largest moment is exerted by members 27 and 29. It is actually such a large value that other stresses can be disregarded to accelerate the simulation process and still get a good image of the capacity of the joint to bear the stresses in such position. In Figure 55, I compare the maximum values of this moment over the joint to gain perspective of the importance of reinforcements and well anchoring.

Table 13 Effects of constrained anchors on joint 36

	case 0	case 19	reduction
full rotation	1084	180	83%
no rotation	358	77	78%
reduction	67%	57%	

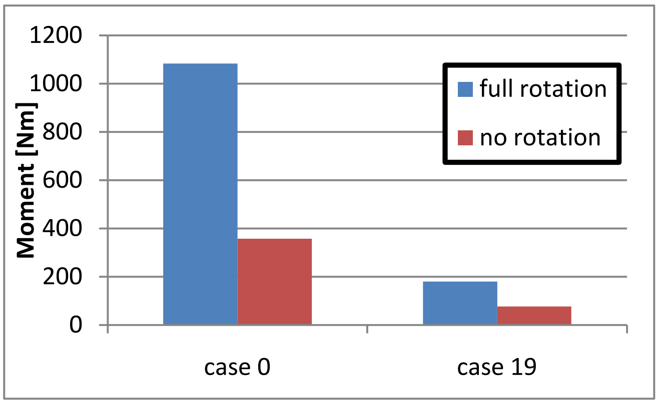


Figure 55 Comparison between case 0 and 19

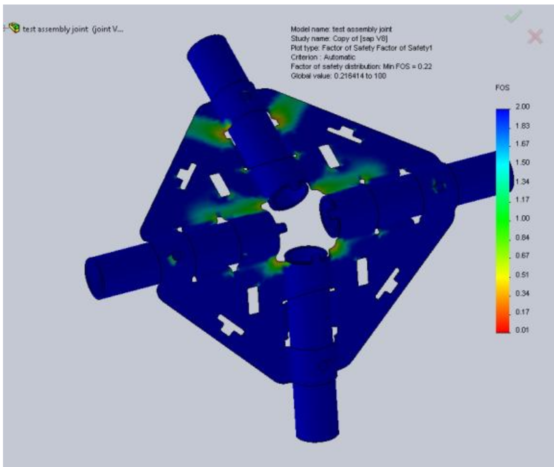
If these results are used as an input into a FEA, the results can easily be compared on the joint. In Table 13 can be observed the stresses subjected to the joint in all of the cases described. As it results evident to the reader, the presence of reinforcements and full constrained anchoring systems, dramatically improve the joints capacity to perform.

Figure 56 shows how the joint is mechanically able to resist extreme weather conditions only when the tent is properly anchored and the reinforcements are in correct position. The results could be improved if external tensors were used but this would increase the area needed for the tent contradicting the original requirements, therefore is only recommended to use external tensors when really needed, as for normal everyday life, the tent will easily stand without the need of them.

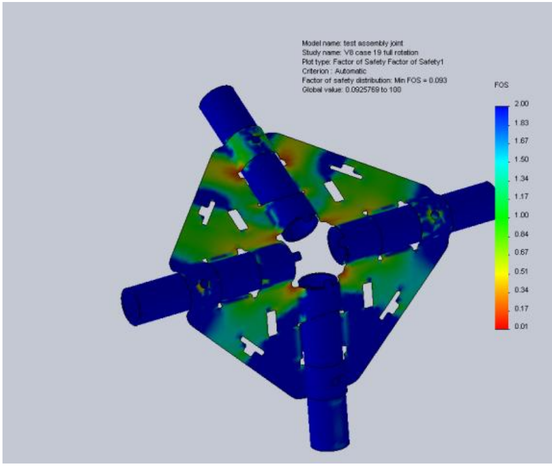
The study used to explain these concepts is Factor of Safety, offered by the simulation software. It helps us to understand the relationships between the stresses on the part with the materials capacity to overcome them. In this way, a factor of safety with a value minor to one could be interpreted as the stress in that particular spot on the part is over the capacity of the material to bear it in the elastic area. It will probably break. It is important to mention that this simulation study does not intend to be a full scale study on the part. However it works to predict and improve the design with the time given for the project.

The results of this small experiment can be consulted in Figure 56 and they show a clear trend, similar to that of Figure 55. We can see how the stress on "case 19 with no rotation" does not exceed the materials capacity where as in "case 19 with full rotation" it is only in very small spaces where the material capacity is exceeded. This is not the case in Case 0 where both types of anchoring will result in a compromise of the joint. As a conclusion we can state that the most important element in the structure is the proper installation of the reinforcements.

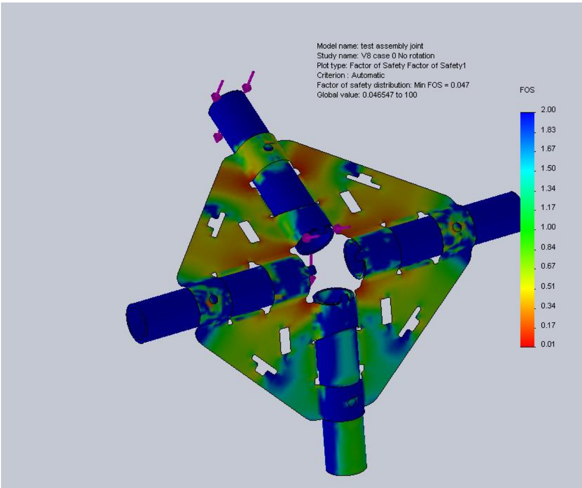
Case 19 No rotation



Case 19 Full rotation



Case 0 No rotation



Case 0 Full rotation

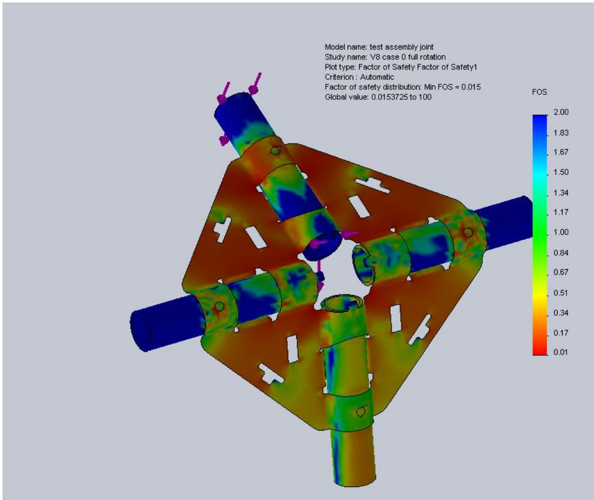


Figure 56 Effects of case 0 and 19 on joint's 36 mechanical behaviors

Anchors

The anchors must provide sufficient hold for the tent in two main ways. On one side it should keep the tent anchored to the ground during strong winds, this function could easily be assisted by extra tensors that although uncomfortable, they would strongly assist to it. On the other side, as expressed strongly during the analysis of the joints, anchors must constrain the rotation of the pipes they hold. This is critical as all the rotary motion the anchors fail to restrain will be directly translated in a moment the joints will have to compensate for. With all this considered, a strong recommendation is made to the emergency relief agencies, to anchor the tents well and to use all the reinforcements stated in the instructions manual.

A full analysis on the anchors would require a huge effort outside the purpose and scope on this thesis. This because of the large variety of places and ground conditions where the tent can be assembled around the globe and the expertise needed for the analysis of ground anchors. Nevertheless, the previous analysis gave results of the resultant stresses of the joints which can be used for future work. These results are shown below in Figure 57 and in an analytical manner in Table 14 and Table 15.

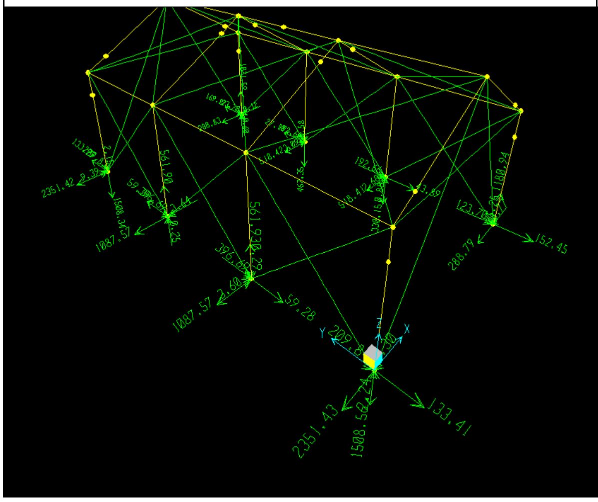
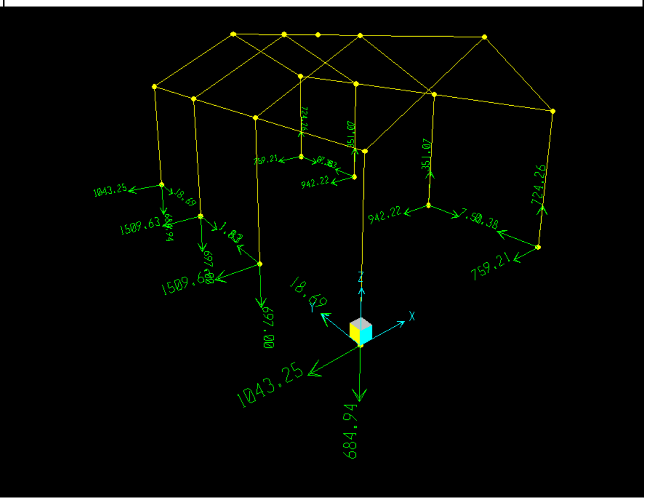
Case 19	Case 0
	

Figure 57 Mechanical reactions on ground anchors

Table 14 Mechanical reactions on ground anchors. Case 19 no rotation

TABLE: Joint Reactions			Case 19 no rotation			
Anchor	**F1**	**F2**	**F3**	**M1**	**M2**	**M3**
	N	N	N	N-m	N-m	N-m
3	-2351.42	133.27	-1508.34	9.39	-209.83	-2.15
5	-288.83	169.27	1071.59	-0.12	-123.7	0.6
30	-1087.57	59.39	561.9	-3.64	-396.69	0.25
32	-518.42	27.1	-467.35	3.09	-192.68	-0.58
35	-1087.57	-59.28	561.93	3.6	-396.69	-0.29
37	-518.41	-43.89	-330.15	2.68	-192.66	0.88
40	-2351.43	-133.41	-1508.56	-9.3	-209.84	2.24
42	-288.79	-152.45	1180.94	-8.77	-123.7	-1.25

Table 15 Mechanical reactions on ground anchors. Case 19 free rotation

TABLE: Joint Reactions			Case 0 Full rotation			
Anchor	**F1**	**F2**	**F3**	**M1**	**M2**	**M3**
	N	N	N	N-m	N-m	N-m
3	-1043.25	-18.69	-684.94	0	0	0
5	-759.21	-0.38	724.26	0	0	0
30	-1509.63	-1.83	-697	0	0	0
32	-942.22	7.53	351.07	0	0	0
35	-1509.63	1.83	-697	0	0	0
37	-942.22	-7.53	351.07	0	0	0
40	-1043.25	18.69	-684.94	0	0	0
42	-759.21	0.38	724.26	0	0	0

6.2 Manufacturing

To ensure the feasibility of the project, all parts must be manufactured within cost to make economic sense. In this section, an overall description of the processes and methods each part requires will be described. It is not intended to explain in detail each technique proposed, but to demonstrate the capacity of production within limits and in accordance to the initial requirements. This section will try to describe part by part, in the same order of the solutions development, how each should be manufactured.

Pipes

Pipes are a very simple standard product that can be easily manufactured all around the world. The only variation would be the implementation of special, super strong steel proposed by the Swedish manufacturer SSAB with a galvanized coating. Except for the material, the pipes can be easily replaceable and manufactured by other companies in most countries. What makes this part special would be that because of the type of material, the weight of the whole part can be reduced considerably.

Several types of joints and anchors proposals were dismissed because they would involve some kind of manufacturing process over the pipes, like holes, gussets or similar. Although this reduced the space for design of the parts, it greatly reduced the production cost of the pipes. Simple became cheap.

Anchors

Anchor manufacturing changes radically between styles and manufacturers. Considering as a base the Auger Anchor and implementing on it the modifications required for a good function of the part, it is easy to foresee the complicated time demanding process that will be used in its fabrication.

If the anchors are produced by a spring manufacturer, they will look like the proposal presented in chapter 5.4. Springs are nowadays made by advanced bending machines that are capable of having controlled geometries at the same time of forming a very complicated shape. It will be able to keep good tolerance control over the production of the anchors. The only extra process would be the incorporation of the helix that screws into the ground. A process that shouldn't result too complicated to the spring manufacturers to include in their lines.

On the other side, a proposal to make an anchor made of a plate, the helix, and a rod would incur in several spaces for misalignment. Another disadvantage I see in this design is the incapacity to press the anchor at the same time of turning it to screw in the ground. However an advantage of this design is the easiness to manufacture in different places plus the superior vertical support it would give to the pipes.

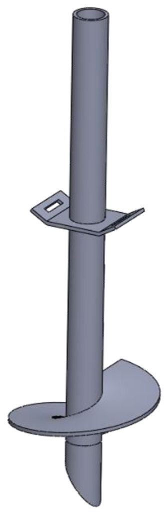


Figure 58 Rod anchor proposal

Joints

Joints are probably the most complicated part to produce in the tent. As an initial idea, it makes it very simple to say that it only requires one stamped part with all the cuts followed by a few bending operations. What makes the manufacturing of this part complicated is the dimensional control during bending that will probably be demanded.

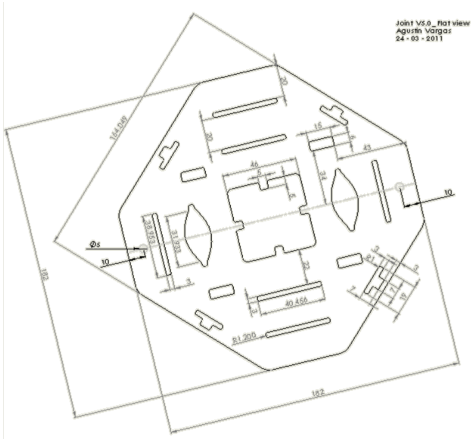


Figure 59 Detailed sketch of Joint

As a first step, the initial cut shape of the joint must be created with very tight tolerances; this means that stamping or laser cut would be required. The flat shape pattern will include all the cuts needed, providing certainty that no further removal of material will be needed and with only bending the part will start to take shape.

The second part of the manufacturing process is the bending of the center line. Only one side can be bent at the time as the radius of each are very different.

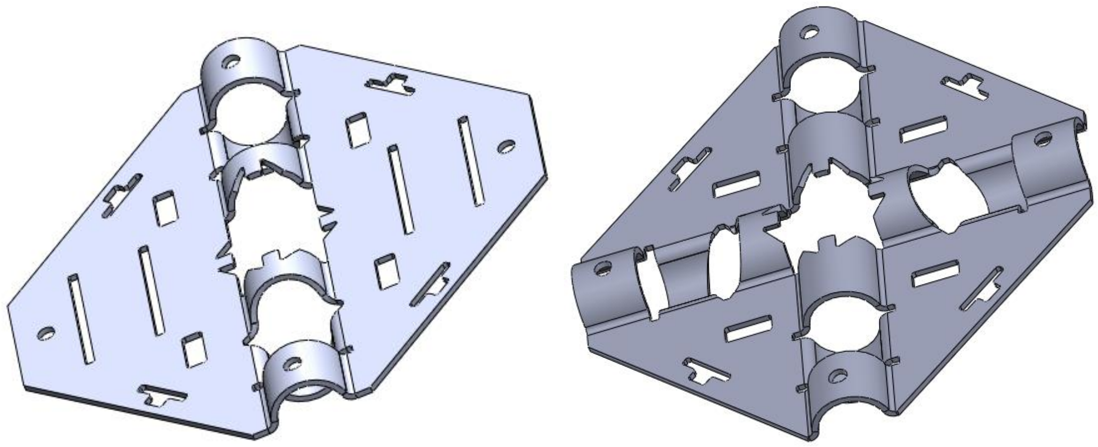


Figure 60 Manufacturing Process of Joint

The small round cuts at the end of the parts are probably the only feature in the design that responds only to a manufacturing requirement. In this type of parts, where bending is required, a strong fastening method must be included to ensure that the part will not move while massive forces are being applied on it. This is the reason why the small holes are positioned in the edges.

Several recommendations were made to improve the manufacturing properties of the design. An example of this is to modify fillets' radius or to allow larger spaces for bending and include fillets in the parts. Although the produced part did not include this recommendations I believe is important to mention them. They can be consulted in Appendix F.

Cross braces

The approach on cross braces is completely different from the rest of the tent. It could be an option to deliver the tent with the tensors cut to the right length but this would be a rather expensive useless activity. In praise of cost and simplified design, it is more convenient to deliver the tent with a certain amount of bracing material enough for one tent. In this way, the refugee builder will have to cut the braces to the proper length and use the rest for other things that might be considered necessary on site, like extra tensors or modification of the tent geometry.

Corner reinforcements

As explained before, corner reinforcements can be of two different kinds. One kind with an extra pipe crossing fastened by joints in the corners and another kind with a stamped long part close to the joint. In the simulation cases, the pipe-corner reinforcement looked considerably more expensive and heavier than the plate-corner reinforcement. In manufacturing we can see the same result.

The pipe-corner reinforcement will require two parts. A pipe exactly like the one used in the rest of the structure which would not add any considerable complications to the packaging or manufacturing requirements. The second part would be a new joint, bended at an angle of 150 degrees. It would have been very comfortable to just place a normal joint but the difference in the bending angle made it impossible for the joint to be fit there. The complications for designing this new joint could result in an expensive process, however, the last step of the normal joint manufacturing can be modified instead of bending at the normal angle of 120 degrees, and it can be bent a little less to leave at 150 degrees reducing costs in development and manufacturing. However, if such a measure is to be taken, a slight modification in the final cuts of the joint should be made to ensure it can remain stacked.

The second corner reinforcement is the plate-corner. Although its design is quite simple and it can be easily fabricated with similar processes to the joints, it still requires tool and production development. If we analyze the cost, weight and volume properties of this solution, we can see that the production per part might be smaller but the tooling development would be larger than the pipe-corner. The weight will be about half for the reinforcement but it is very hard to stack and pack it in a matter that it won't get damaged or occupy a lot of space as they bend quite easily.

All considered, from a manufacturing point of view, the pipe-corner reinforcement seems like a better choice. It uses parts and production systems that are already in use so it simplifies considerably the development process plus it adds considerable strength to the tent.

6.3 Assembly

Once the tent has been deployed to the camp site, the next challenge for organizations is to distribute it and ensure its proper assembly on site. As seen before, the loads the tent will sustain are quite elevated; therefore the camp managers must ensure that they are well built. Based on emergency manuals, NGOs usually create small groups of people to whom they will explain the procedures for building the tents, and then this group of people will show others and the procedure caries on. (UNHCR, 2007)

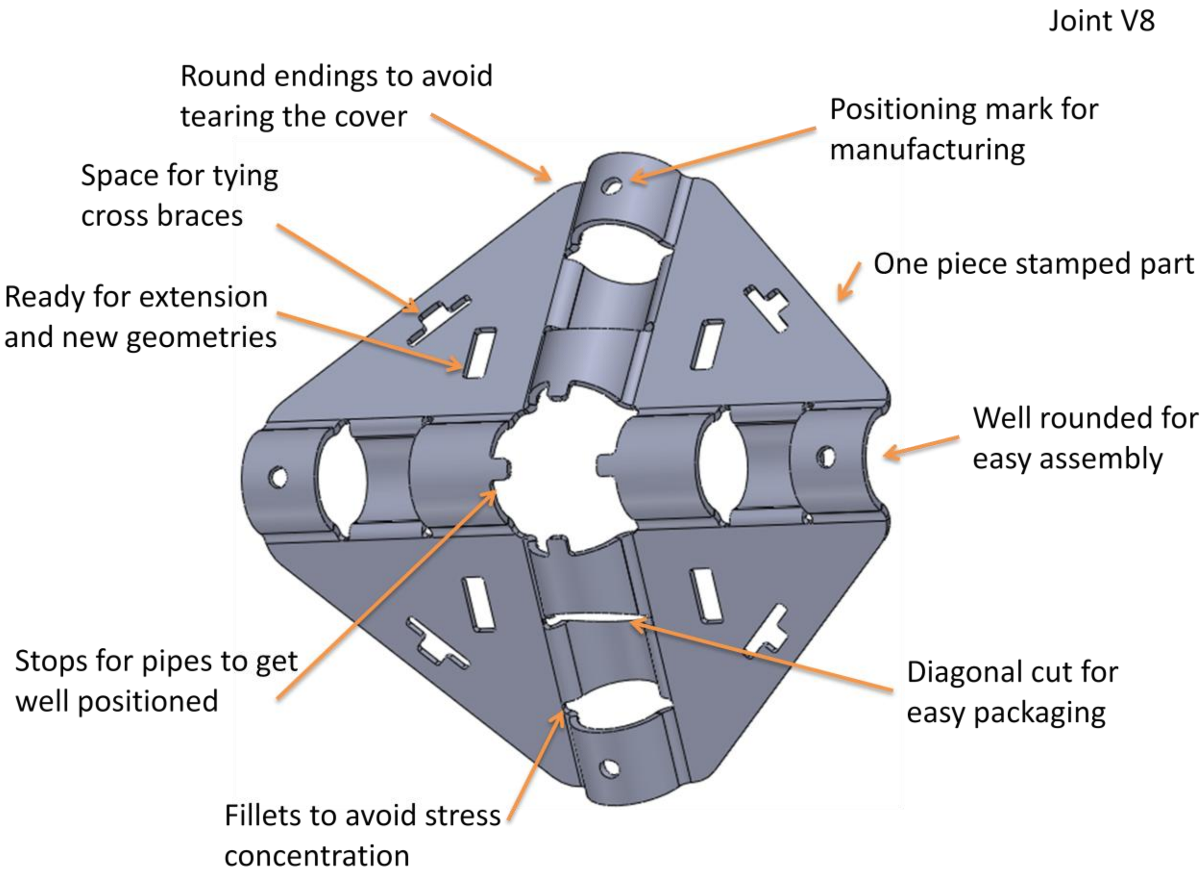
For this course of action to work and to achieve the quality expected from the product, the tent geometry should be easy and self explanatory. No printed instructions should be needed (although they must be included) and everyone, regardless of culture or background should be able to assemble it properly. A good design would be the one that if a mistake is made while assembly, the user can realize that and correct his mistake without compromising the integrity of the parts misassembled. (Norman, 1988)

Figure 61 Assembly mistake example

As the parts to be used are quite simple, only two mistakes can be foreseen in the assembly of the tent. One mistake is to connect the pipes in different places of the joint. This mistake happened a couple of times in the trials we did with the first prototypes, however it is only a minor mistake as correcting it will only take a few seconds, plus it is very easy to realize someone has made the mistake. The tent cannot be assembled if the joints are misplaced.

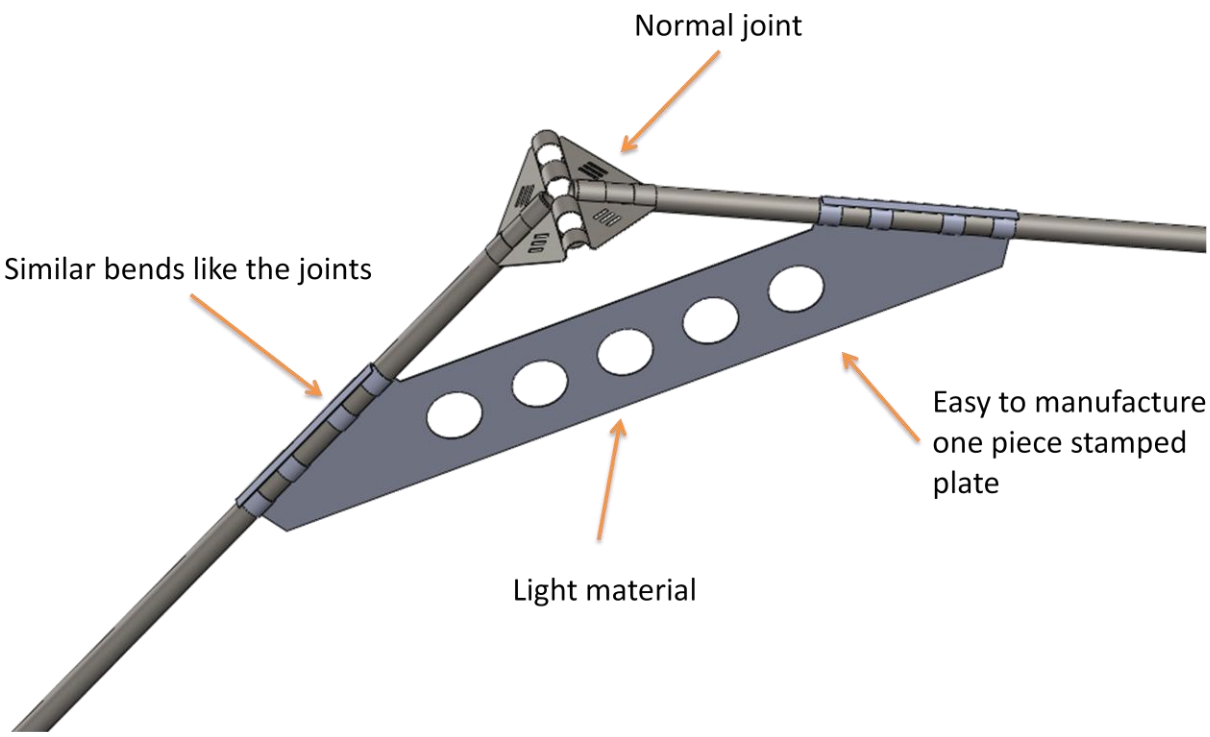
The second possible assembly mistake could happen if the pipe-corner reinforcements are used (see chapter 4.8). The joints these reinforcements will use are very similar to the ones the rest of the tent will use. If not made different, the possibility of someone using the wrong part and not realizing it is very big. To avoid this, a strong recommendation is made to use a different cutting pattern that would make them easy to distinguish between each other.

6.4 Design Details

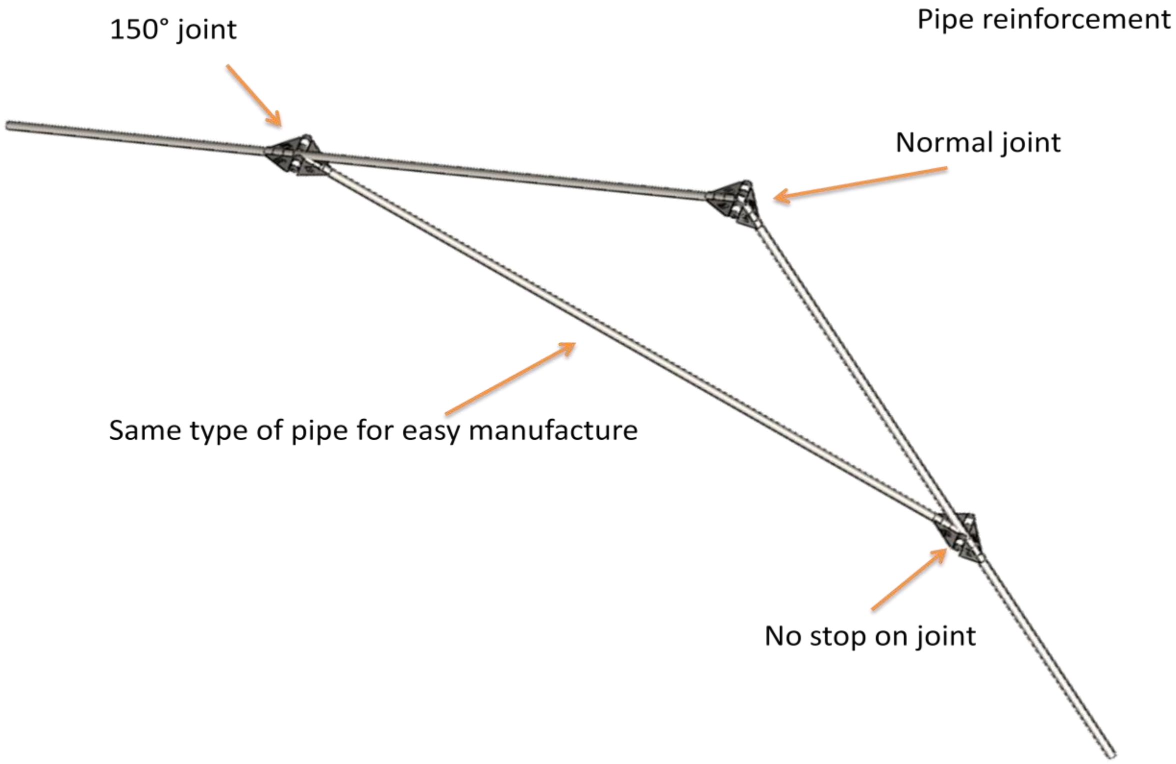


The final design of the joints complies with all stated desires and supports the structural requirements. It is very light in relation to the stress capacity. All required joints are easy to pack and do not affect in any way the cover due to the rounded corners. In case of needed, simple parts can be used to expand the tent using the same joints. As it is easy to see, no special tools are required to assemble them, however they can be welded if a permanent solution is needed. Different kinds of braces can be attached to it and their geometry is self explanatory to avoid requiring assembly instructions.

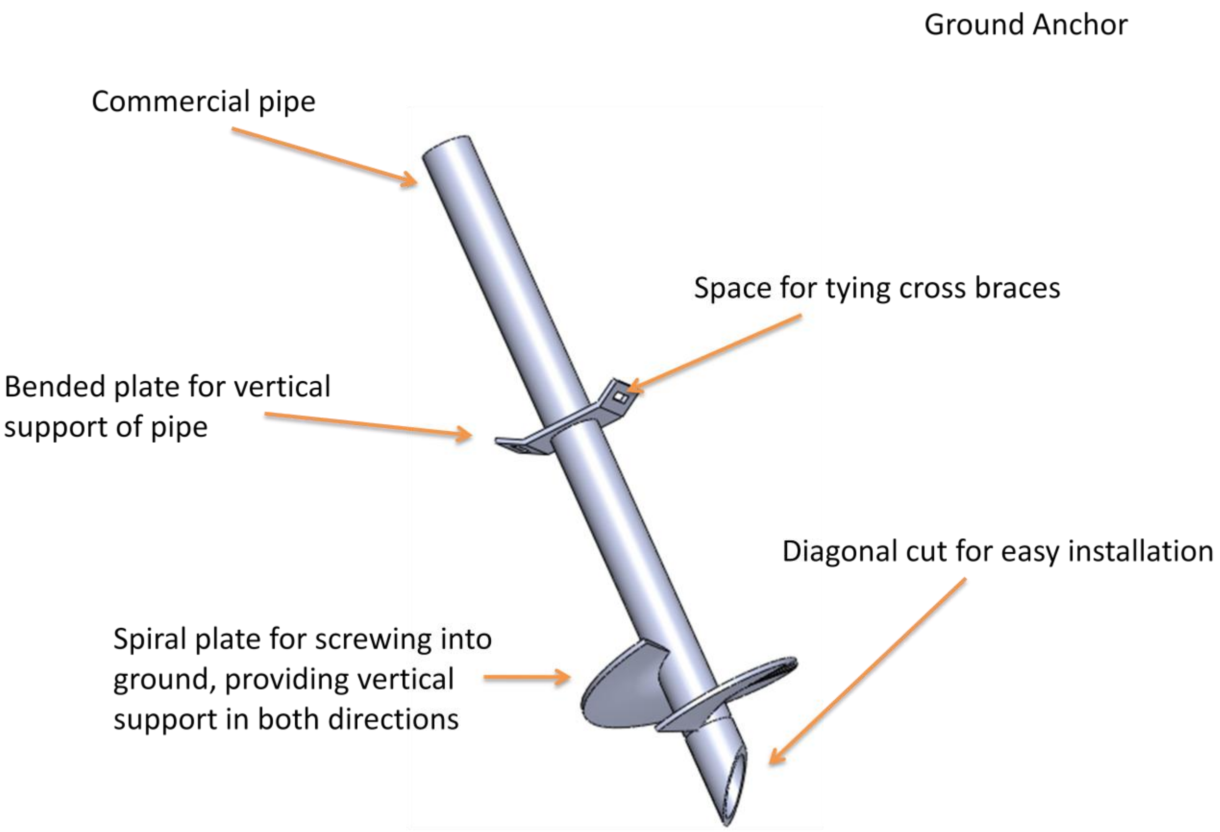
Plate corner reinforcement



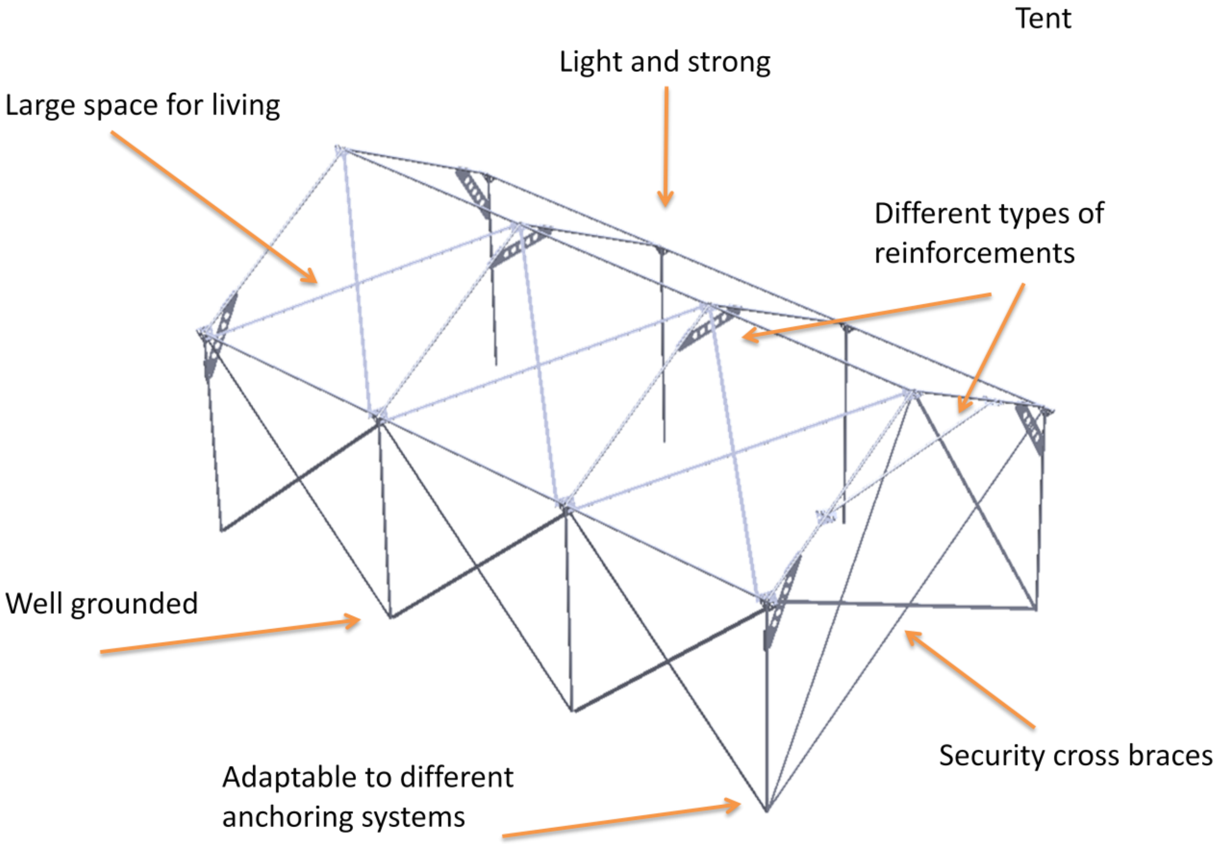
Corner reinforcements respond directly to the structure requirements. Together with the reinforcement configuration, they comply with the requirement list and the best choice in this case, in my opinion, it's the plate reinforcements. They are lighter and easier to assemble plus they are the most inexpensive solution. The drawback of this design is the development of specialized tooling to shape the sheet metal; however it is exactly the same process as the joints, avoiding the need for different manufacturing capabilities.



As an alternative to the plate corner reinforcement, this configuration uses the already existing joint and pipes to provide the tent with the sturdiness it needs for demanding environments. It is however, disadvantageous in a few aspects. It increases considerably the weight of the tent and the existence of joints that are bent at a different angle will probably result in assembly mistakes that cannot easily be detected. It is also a more expensive solution and does not provide for such a larger increase of stability to compensate for the disadvantages it brings.



The final anchors diverge considerably from the first conceived design. They still have a screw type front to provide for vertical support in both directions but instead of having a thin metal rod, a pipe is used to support the whole structure. This brings the advantage of improving the rotational fixation of the structural pipe, a very important feature as explained previously. All this good features come at a very high price. The thickness of the pipes makes the anchors very hard to place and there is no way to help twist the anchor as there was in the previous design. Also the special design will need special manufacturing training and no off-the-shelf solution can be adapted to it. All considered, the anchors still comply with the desires and requirements and is only the test on site and through time that could prove otherwise.



This is the final result of this thesis. It represents a design that complies to the stated requirements by the most important organizations in the world, plus it brings new advantages without sacrificing anything. The materials used are of very high quality, ensuring their service far long after the required time plus it can expand with the input of local materials and labor helping develop the local community.

7. Requirement Evaluation

In this section, the design at the moment of finishing this work will be evaluated against the full list of relevant requirements. The code in Table 16 represents whether or not the requirement was fulfilled, something is missing or is not possible to know. The reader should be reminded of the delimitations of the project as not all requirements are relevant to the developed frame. Therefore, this list of requirements is considerably smaller than the presented at the beginning of the project.

As there are many requirements stated for the whole tent (frame + cover) it would be considered that the cover will also help comply to the requirements if the frame complies.

Table 16 Req. Evaluation	
✓	Fulfilled
○	Unknown
χ	Failed

7.1 Evaluation of Social Requirements

Sphere Project

- ✓ The initial covered floor area per person is at least 3.5m2
- ✓ Locally sourced materials and labor are used without adversely affecting the local economy or environment.
- ✓ The type of construction and materials used enable the maintenance and upgrading of individual household shelters using locally available tools and resources.

UNHCR

- ✓ 29 The design shall allow for the introduction of fuel burning stoves, including a fireproof and waterproof flue manifold.
- ✓ 49 Shelters shall not involve materials that are toxic to humans, even when cut or modified for later re-use.
- ✓ 61 The design shall facilitate the local adaptation of wall and roofing materials, such as mud brick side walls, local matting, or thatch.

7.2 Evaluation of Engineering Requirements

Sphere Project

- ✓ Construction and material specifications mitigate against future natural disasters.

Shelter Centre

- ✓ Complete package has a mass between 40 kg and 80 kg
- ✓ Total shelter is in one package which can be broken down to smaller packages, suitable for transport for 2 people
- ✓ Complete shelter has packed volume between 0.3m3 and 0.5m3.
- ✓ Longest dimension of packed shelter is no more than 200cm.
- ✓ At least 4 packed shelters can fit onto a 120x80cm Euro pallet.
- ✓ The packed shelters can be packed vertically onto a 120x80cm Euro pallet.
- ✓ The shelter should be of sufficient size to house a family of 5, with between 3.5m2 and 4.5m2 of covered living area.
- ✓ The standing height of the covered space is a minimum of 180cm over at least 60% of the covered floor area.
- ✓ There are no guy ropes or other trip hazards around the shelter.
- ✓ The shelter can be distributed as a complete package, ready to put up, with all components included and all required tools.
- ✓ The frame is strong enough to support 6 to 8 30kg hanging live loads.

UNHCR

- ✓ A complete shelter package shall have a mass between 40kg and 80kg.
- ✓ The total shelter shall be in one package which contains smaller packages broken down into parcels of weights suitable for transport by two people.
- ✓ A complete shelter package shall have a packed volume between 0.3m3 and 0.5m3.
- ✓ The longest dimension of a packed shelter shall be no more than 200 cm *(perhaps 220 or 228 cm, currently under revision).*
- ✓ It shall be possible to fit at least four packed shelters onto a 120 x 80cm Euro pallet.
- ✓ It shall be possible to stack the packed shelters vertically onto a 120 x 80cm Euro pallet.
- o It shall be possible to keep shelters in storage for at least five years without damage or changes reducing the functional capacity.

  No test has been made but design indicates it can
- o The shelter shall be capable of being produced fast enough to respond suitably to a humanitarian crisis.

  No large production has been made
- ✓ The structure shall have sufficient redundancy so that if the covering or one fixing fails, the shelter will remain upright.
- ✓ The erected shelter, with all doors and windows closed shall be able to withstand a wind speed of 18m/s in any direction. After application of

the load, the tent shall return to its original shape and position without damage.

- ✓ The shelter shall withstand 300 N/m^2 of snow loading without damage or changes reducing the functional capacity *(reduced from 1,500 N/m^2 due to inappropriate source).*
- ✓ In warm, humid climates the roof shall have a reasonable slope for rain water drainage.
- o There shall be provision to trench the sod cloths into the ground to increase the stability of the shelter.

  Further research on anchors required
- o From moment of deployment, the structure shall last for a minimum of 36 months, the covering and liner shall last for a minimum of 18 months

  No test has been made
- ✓ The shelter shall withstand temperatures between -30°C to +55°C without damage or changes reducing the functional capacity.
- ✓ The shelter shall be large enough for a family of five and have between 3.5m^2 and 4.5m^2 of covered living area.
- ✓ The standing height for the covered space shall be a minimum of 180cm over at least 60% of the covered floor area.
- ✓ There shall be no guy ropes, or other trip hazards around the shelter.
- o It shall be possible for two untrained adults to assemble the shelter without expert supervision.

  It should be possible but trials should be made
- ✓ It shall be possible to connect the shelter to another of the same type to increase the covered area.
- o The design shall facilitate the local adaptation of wall and roofing materials, such as mud brick side walls, local matting, or thatch.

  Research about physical properties of such material required
- o The frame shall be strong enough to support the dead load of sheet roofing materials *(value to be determined)*.
- o The frame shall be strong enough to support 6-8 30kg hanging live loads
  - o *The test was not made but is expected to work*
- o The number of different types of components shall be kept to a minimum.

  Ambiguous requirement
- o The total number of components shall be kept to a minimum.

  Ambiguous requirement
- ✓ Components shall be interchangeable where possible.
- χ Components shall be available globally, or appropriate materials, tools and skills should be available for their local manufacture and repair.

  Special tooling is required for joints and anchors
- ✓ The design shall maximize the number of components and materials that can be maintained and repaired with non-specialist skills and equipment.

7.3 Evaluation of Environmental Requirements

Shelter Centre

- ✓ The shelter does not involve materials that are toxic to humans, even when cut or modified for later reuse.
- ✓ The shelter does not involve materials that are toxic by burning or burying, and shall not pollute the ground water table or enter the food chain.

UNHCR

- ✓ Shelters shall not involve materials that are toxic to humans, even when cut or modified for later re-use.
- o The environmental impact resulting from the manufacturing or disposal of shelters shall be minimized.

  Ambiguous requirement
- ✓ Shelters shall not involve materials that are toxic by burning or burying, and shall not pollute the ground water table or enter the food chain.

8. Future Work

After the conclusion of this thesis, there are still a few things that remain to be worked on in the Emergency Housing Project. This can be divided into three areas of improvement. On the first place, there are still parts missing to make this a home. In second place, the mechanical analysis could be deepened. Finally, an onsite test with users and stake holders must be conducted as a final guaranty of the success of the product.

The overall cover of the tent was not part of this thesis, but it is important that a proper tailored cover whether made of fabric, plastic sheeting or hard panels, must be developed and accompany the structure to be a useful tent. This cover should comply with all previous stated requirements and regulations from the humanitarian agencies, plus it should fit within the developed frame.

Anchors remain a gray area. Although the choice of Auger anchors is in accordance to several other similar products and projects around the world, and they are the most versatile choice, specialized anchors depending on the ground conditions of a particular case could result in a competitive advantage. The design of the tent allows for a great flexibility in anchor design, a design resource that should be exploited by those who continue this work.

On a different level, a full scale mechanical test must be conducted on the part. These tests should certainly include fatigue analysis, especially in the anchors and joints, to evaluate the expected life length of the overall tent. RD&T analysis must also be developed before full scale production. The risk of not having a proper tolerance control during design and production could result in useless tents due to their poor quality or in wrongly fixed parts because they were forced to assemble.

A full mechanical virtual test on the tent could improve the predictability of the components. It could help to evaluate, in a more thorough manner the advantages of including gussets in the joints plus it might help to improve the security of the tent.

After every design process, a full production process must be developed as well. Still to see are the logistics, production lines and facilities needed for the fast and correct production of the tent, both for stocking as for emergency production. Also in this line of thought, it is mandatory to do a test run of several prototypes to ensure the capacity of such process.

At the end, the most important test to overcome is that of those who will transform it in a home. The organizations on site that depend on this product to provide for those on trouble and the human beings that in time of despair would need it to performing excellent to have a dignified home. It is only on the field where the true value of this proposal will be proven.

9. Conclusions and Personal Review

A light weight structure frame has been developed for emergency housing. This work proves that there is a lot of space for improvement of the solutions actually used for emergency relief, especially in the case of housing.

This work, also demonstrates that the orderly use of concrete product development techniques greatly improves the result and the development process. Requirements were stated and reviewed throughout the whole process to ensure that the final outcome will satisfy its users and stakeholders. Among the different development tools used for the project, those that provided a better output were design of experiments, prototyping and rain of ideas.

The close collaboration with people from different knowledge areas also proved its value. The input from architects made my project take a different view and oversee a different horizon. The point of view of humanitarian organizations and experts traced a road that only with engineering knowledge would have never been patterned.

From a personal perspective, the method followed resulted in a good result in the expected time, however at some times the amount of work seamed overwhelming. The close collaboration with other students, working on their thesis inside the project, helped a lot however having a partner would have allowed for a faster flow of ideas and the enrichment of them. The aim of the project, and its potential outcome in a real problem was fundamental. It was highly motivating to work in this project.

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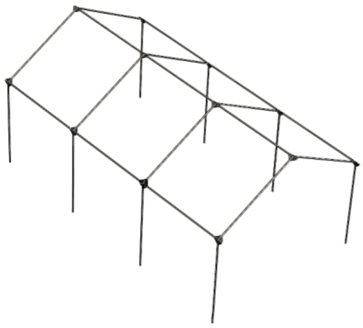
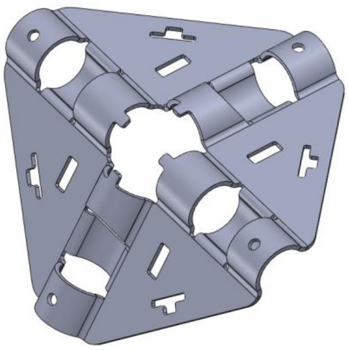
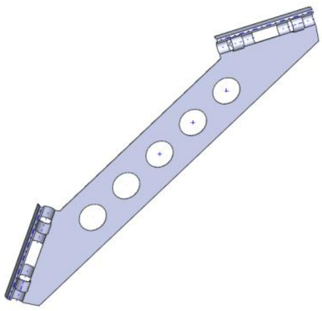
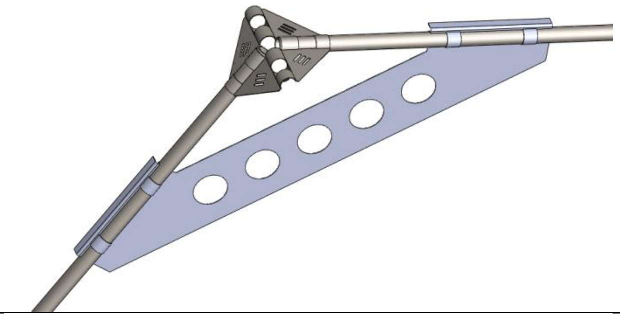
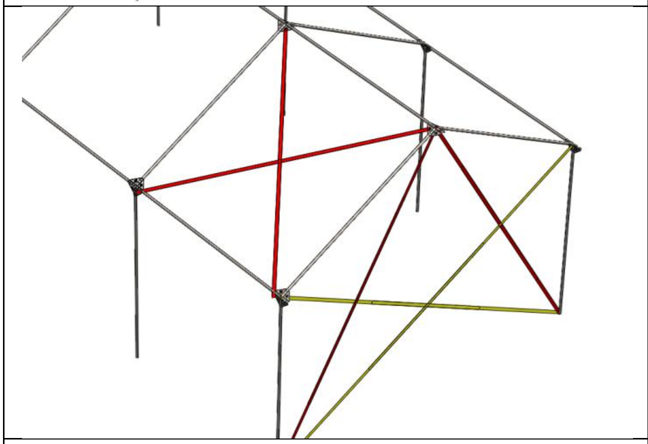
11. Appendix

Appendix A
Nomenclature of Parts.

	Light Weight Steel Frame
	Joint
	Pipe
	Corner-Plate Reinforcement

	Corner Plate Assembly
	Pipe-Corner Assembly
	Cross Braces
	Auger Anchors

Appendix B
Tent Requirements UNHCR

Total weight and packed size

The shelter will need to be handled by both the intended beneficiaries, and agency staff. Beneficiaries may have limited access to transportation, making it difficult to move the shelter long distances. Agency staff will be looking to make the most effective and efficient use of their supply chains.

1 A complete shelter package shall have a mass between 40kg and 80kg.
2 The total shelter shall be in one package which contains smaller packages broken down into parcels of weights suitable for transport by two people.
3 A complete shelter package shall have a packed volume between 0.3m^3 and 0.5m^3.
4 The longest dimension of a packed shelter shall be no more than 200 cm *(perhaps 220 or 228 cm, currently under revision).*
5 It shall be possible to fit at least four packed shelters onto a 120 x 80cm Euro pallet.
6 It shall be possible to stack the packed shelters vertically onto a 120 x 80cm Euro pallet.

Storage

It is unknown when the shelters will be needed, and it is therefore important that agencies are able to stockpile shelters with confidence in advance of a response.

7 It shall be possible to keep shelters in storage for at least five years without damage or changes reducing the functional capacity.

Marking

Shelters will be handled by many actors, and it is important for logistics and program staff to understand the type and performance of the shelters, including where they were made, who they were made by, their size, their thermal performance, what components they have, whether they have already been deployed, and how long they've been in storage.

8 Shelters shall have space to mark which particular design it is, how large the useable area of the shelter is, as well as how many people it can accommodate.
9 Shelters shall have space to mark means of transport, time in storage, and conditions of storage
10 Shelters shall be marked with the name or trademark of the manufacturer, and the date of manufacture.
11 The shelter shall indicate that it is or isn't mosquito proofed.
12 These instructions shall be in English, French, and any other appropriate language.
13 It shall be easy to print the humanitarian organization/donor logo on the outer fly and door of the shelter.

Availability

Not all organizations stockpile shelters, and rapid-onset disasters require that shelters are able to be procured in a quick and timely fashion by implementing agencies within weeks, if not days, of an emergency.

14 The shelter shall be easy to obtain from different manufacturers under competitive bidding.
15 The shelter shall be capable of being produced fast enough to respond suitably to a humanitarian crisis.

Recipients of stockpiled hot and cold family shelter shall have sufficient covered space to provide dignified accommodation. Essential household activities can be satisfactorily undertaken, and livelihood support activities can be pursued as required.
The design of the shelter shall be acceptable to the affected population and provide them with sufficient thermal comfort, fresh air and protection from the climate to ensure their dignity, health, safety and well-being. The following physical requirements will prove useful to humanitarian staff defining and implementing a strategy involving stockpiled transitional family shelters. This will also provide the commercial sector with a further understanding of the constraints and opportunities facing humanitarian shelter programs.

Integrity

The shelter, including the covering, liner, frame and floor shall be consistent with known climatic conditions, be capable of withstanding appropriate wind loading, rain-loading and accommodate snow-loading in cold climates.

16 The structure shall have sufficient redundancy so that if the covering or one fixing fails, the shelter will remain upright.
17 The erected shelter, with all doors and windows closed shall be able to withstand a wind speed of 18m/s in any direction. After application of the load, the tent shall return to its original shape and position without damage.
18 The shelter shall withstand 300 N/m² of snow loading without damage or changes reducing the functional capacity *(reduced from 1,500 N/m² due to inappropriate source).*
19 The cover shall withstand 1500mm water column minimum *(may need separate values for synthetics/natural fibers, to be confirmed)*.
20 The ground sheet shall withstand 1500mm water column minimum.
21 In warm, humid climates the roof shall have a reasonable slope for rain water drainage.
22 There shall be provision to trench the sod cloths into the ground to increase the stability of the shelter.

Durability

Often in an emergency, a household will have to make do with what they are initially distributed in the emergency phase for some time after. It is therefore important that the shelter design is durable enough to withstand well beyond the typical emergency phase.

23 From moment of deployment, the structure shall last for a minimum of 36 months, the covering and liner shall last for a minimum of 18 months *(additional investigation undertaken to determine cost burden of 12-, 18-, or 24-month liner lifetime).*
24 The shelter shall withstand temperatures between -30ºC to +55ºC without damage or changes reducing the functional capacity.
25 All outer fabrics shall provide a minimum resistance to natural sunlight. This requirement is deemed to be met if, after artificial weathering in accordance with ISO 4892-2 and applying the test parameters specified in Table 8, the breaking strength and the resistance to penetration by rain are not more than 30% below the minimum value applicable to the shelter.
26 Inner fabrics shall have a minimum breaking strength of 30 daN for warp and weft when tested in accordance with ISO 13934-1 or ISO 1421.

Useable area

Space within the shelter, and immediately surrounding it, shall provide for sleeping, washing and dressing; care of children and elderly; the storage of food, water, household possessions; and cooking and eating indoors when required.

27 The shelter shall be large enough for a family of five and have between 3.5m^2 and 4.5m^2 of covered living area.
28 The standing height for the covered space shall be a minimum of 180cm over at least 60% of the covered floor area.
29 The design shall allow for the introduction of fuel burning stoves, including a fireproof and waterproof flue manifold.
30 It shall be possible to insulate the floor, walls and roof of the shelter.
31 Provision will be made for semi-enclosed and shaded cooking areas and provision for fixed minimum ventilation of the interior, to reduce cases of Acute Respiratory Infections (ARIs).
32 Storage pockets shall be integrated into the inner liner of the shelter.
33 There shall be no guy ropes, or other trip hazards around the shelter.

Ventilation

Adequate ventilation shall be provided within the shelter design to maintain a healthy internal environment and to limit the risk of transmission of diseases, such as tuberculosis spread by droplet infection. Ventilation should be maximized in hot-climates to reduce inside temperature, and minimized in cold-climates to retain heat within the shelter.

34 Minimum ventilation shall be achieved through an unobstructed aperture with a total area equivalent to 0.01m^2.
35 Design shall allow for maximum and minimum air changes per hour to avoid discomfort of occupants, air changes per hour should be not less than 7, but not more than 14.
36 Shelters shall have a ceiling to provide an adjustable air gap for insulation and ventilation.
37 All doors and openings shall be adjustable to control light and heat gain or loss.

38 In hot, dry climates the shelter should have a double-skinned roof with ventilation between the layers to reduce radiant heat gain. The distance between the layers should be at least 100mm.
39 In warm, humid climates the shelter design shall maximize air flow.
40 In cold climates, air flow through the shelter shall be kept to a minimum, while also providing adequate ventilation for space heaters, or cooking stoves.
41 In cold climates, the shelter shall have internal compartments in order to minimize heat loss through infiltration.

Fire safety

Fire is of tremendous concern with a population living in tents. Safe shelter, appropriate heat and light emitting NFIs, and public information campaigns are all of critical importance to mitigate injury and damage resulting from fire.

42 The shelter shall have two opposite doors to facilitate escape in the event of fire.
43 It shall be possible to exit the shelter within 30 seconds when all doors are fully closed.
44 The shelter shall not ignite when tested in accordance with ISO 6940 and exposed to a test flame for 10 seconds, in the new condition and also after artificial weathering in accordance with ISO 4892-2.

Vector control

The patterns of shelter used by beneficiaries should inform the shelter design and subsequent vector control measures. Typical risks are posed by mosquitoes, rats and flies and pests such as snakes, scorpions and termites.

45 All doors and openings shall be protected against insects.
46 The shelter shall have a 10cm vertical edge around the base of entry points in order to impede the entry of insects.
47 The shelter must be mosquito proofed in an area long and broad enough for the intended occupancy to sleep in.
48 There shall be fixings for additional or replacement mosquito nets to be hung.

Environmental toxicity

Shelters will be modified, passed on, and ultimately disposed of. At no point in this process can the shelter cause harm to the user, or the environment.

49 Shelters shall not involve materials that are toxic to humans, even when cut or modified for later re-use.
50 The environmental impact resulting from the manufacturing or disposal of shelters shall be minimized.
51 Shelters shall not involve materials that are toxic by burning or burying, and shall not pollute the ground water table or enter the food chain.

Color

Not all colors have the same meaning to all people, and care must be taken to ensure the colors used in shelters are culturally appropriate.

52 Military or camouflage colors shall not be used *(categorical restriction on green, beige and white removed).*
53 Cultural and political sensitivities shall be taken into account, for example in the use of colors used in national or factional flags.

The design of the shelter shall be acceptable to the affected population and provide them with an adaptable, repairable and dignified living space.
The following social requirements will prove useful to humanitarian staff defining and implementing a strategy involving culturally appropriate stockpiled hot and cold family shelter. This will also provide the commercial sector with a further understanding of the variety of cultures to which these shelters will be deployed.

Privacy

Existing local practices in the use of covered living area, for example sleeping arrangements and the accommodation of extended family members, should inform the covered area required.

54 It shall be possible to sub-divide the internal volume in order to increase visual privacy, whilst maintaining cross-ventilation.
55 A fully closed shelter shall allow sufficient light to enter without compromising privacy.
56 At night, it shall be possible to use artificial lighting within the shelter without compromising privacy.

Buildability

Shelter materials and design may often be unfamiliar to the recipients. It is important that the design, where possible, be familiar and that the method of erection straight forward.

57 It shall be possible for two untrained adults to assemble the shelter without expert supervision.
58 The shelter shall be distributed complete, ready to put up, with all components included and all appropriate tools.
59 Each shelter shall be accompanied by instructions for use with explanatory sketches or drawings, suitable for multi-cultural and multilingual use in a variety of climatic and physical contexts, including on different topographies and ground conditions. In particular, these instructions shall ensure that erection and maintenance are well understood by an untrained adult. Shelters shall also be accompanied with instructions for the safe disposal of the components

Adaptability and reparability

As emergency shelter response typically provides only a minimum level of enclosed space and materials assistance. Affected families will need to seek alternative means of increasing the extent or quality of the enclosed space provided. The design and materials shall enable individuals to incrementally adapt or upgrade the shelter or aspects of the design to meet their needs and to undertake repairs using locally available tools and materials.

60 It shall be possible to connect the shelter to another of the same type to increase the covered area.

61 The design shall facilitate the local adaptation of wall and roofing materials, such as mud brick side walls, local matting, or thatch.
62 The frame shall be strong enough to support the dead load of sheet roofing materials *(value to be determined)*.
63 The frame shall be strong enough to support 6-8 30kg hanging live loads *(currently under investigation by Losberger).*
64 The number of different types of components shall be kept to a minimum.
65 The total number of components shall be kept to a minimum.
66 Components shall be interchangeable where possible.
67 Components shall be available globally, or appropriate materials, tools and skills should be available for their local manufacture and repair.
68 Insulating materials shall be incorporated into the shelter when temperatures fall below a comfortable level
69 The design shall maximize the number of components and materials that can be maintained and repaired with non-specialist skills and equipment.
70 The shelter shall include a repair kit, with appropriate tools, spare components and material.
71 The design shall maximize the number of component materials that are suitable for later re-use, upgrading, modification or reconstruction on return.
72 Use of zippers and fixing methods such as proprietary clips and Velcro shall be minimized for use in functions that must be used frequently, such as doors and windows.

Appendix C
Tent Requirements Sphere Project

This appendix was taken from the minimum standards handbook and its purpose is to help explain the requirements of the humanitarian relief organizations that belong to it and its relationship with this project. (The Sphere Project, 2004)

The Sphere initiative was launched in 1977 by a group of humanitarian NGOs and the Red Cross and Red Crescent movement, who framed a Humanitarian Charter and identified Minimum Standards to be attained in disaster assistance, in each of five key sectors (water supply and sanitation, nutrition, food aid, shelter and health services). This process led to the publication of the first Sphere handbook in 2000. Taken together, the Humanitarian Charter and the Minimum Standards contribute to an operational framework for accountability in disaster assistance efforts.

The cornerstone of the handbook is the Humanitarian Charter, which is based on the principles and provisions of international humanitarian law, international human rights law, refugee law and the Code of Conduct for the International Red Cross and Red Crescent Movement and Non-Governmental Organizations (NGOs) in Disaster Relief. The Charter describes the core principles that govern humanitarian action and reasserts the right of populations affected by disaster, whether natural or man-made (including armed conflict), to protection and assistance. It also reasserts the right of disaster-affected populations to life with dignity. The Charter points out the legal responsibilities of states and warring parties to guarantee the right to protection and assistance. When the relevant authorities are unable and/or unwilling to fulfill their responsibilities, they are obliged to allow humanitarian organizations to provide humanitarian assistance and protection.

Shelter and settlement standard 3: covered living space

People have sufficient covered space to provide dignified accommodation. Essential household activities can be satisfactorily undertaken, and livelihood support activities can be pursued as required.

Key indicators

- The initial covered floor area per person is at least 3.5m2
- The covered area enables safe separation and privacy between the sexes, between different age groups and between separate families within a given household as required
- Essential household activities can be carried out within the shelter
- Key livelihood support activities are accommodated where possible

Shelter and settlement standard 4: design

The design of the shelter is acceptable to the affected population and provides sufficient thermal comfort, fresh air and protection from the climate to ensure their dignity, health, safety and well-being.

Key indicators

- The design of the shelter and the materials used are familiar where possible and culturally and socially acceptable
- The repair of existing damaged shelters or the upgrading of initial shelter solutions constructed by the disaster-affected population is prioritized.
- Alternative materials required to provide temporary shelter are durable, practical and acceptable to the affected population

- The type of construction, materials used and the sizing and positioning of openings provides optimal thermal comfort and ventilation.
- Access to water supply sources and sanitation facilities, and the appropriate provision of rainwater harvesting, water storage, drainage and solid waste management, complement the construction of shelters
- Vector control measures are incorporated into the design and materials are selected to minimize health hazards

Shelter and settlement standard 5: construction

The construction approach is in accordance with safe local building practices and maximizes local livelihood opportunities.

Key indicators

- Locally sourced materials and labor are used without adversely affecting the local economy or environment.
- Locally derived standards of workmanship and materials are achieved
- Construction and material specifications mitigate against future natural disasters.
- The type of construction and materials used enable the maintenance and upgrading of individual household shelters using locally available tools and resources.
- The procurement of materials and labor and the supervision of the construction process are transparent, accountable and in accordance with internationally accepted bidding, purchasing and construction administration practices.

Shelter and settlement standard 6: environmental impact

The adverse impact on the environment is minimized by the settling of the disaster-affected households, the material sourcing and construction techniques used.

Key indicators

- The temporary or permanent settling of the affected population considers the extent of the natural resources available
- Natural resources are managed to meet the ongoing needs of the displaced and host populations
- The production and supply of construction material and the building process minimizes the long-term depletion of natural resources.
- Trees and other vegetation are retained where possible to increase water retention, minimize soil erosion and to provide shade.
- The locations of mass shelters or temporary planned camps are returned to their original condition, unless agreed otherwise, once they are no longer needed for emergency shelter use.

Appendix D
Tent Requirements Shelter Centre

Total weight and packed size

- Complete package has a mass between 40 kg and 80 kg
- Total shelter is in one package which can be broken down to smaller packages, suitable for transport for 2 people
- Complete shelter has packed volume between 0.3m3 and 0.5m3.
- Longest dimension of packed shelter is no more than 200cm.
- At least 4 packed shelters can fit onto a 120x80cm Euro pallet.
- The packed shelters can be packed vertically onto a 120x80cm Euro pallet.

Useable area

- The shelter should be of sufficient size to house a family of 5, with between 3.5m2 and 4.5m2 of covered living area.
- The standing height of the covered space is a minimum of 180cm over at least 60% of the covered floor area.
- The inner liner has integrated storage pockets.
- There are no guy ropes or other trip hazards around the shelter.

Ventilation

- Minimum ventilation shall be achieved through an unobstructed aperture with a total area equivalent to 0.01m2.
- All doors and openings are adjustable to control light and heat gain or loss.

Fire Safety

- The shelter has two opposite doors to facilitate escape in case of fire.
- It is possible to exit the shelter within 30 seconds when all doors are fully closed.

Vector control

- The shelter has a 10cm vertical edge around the base of entry points to impede the entry of insects.

Environmental Toxicity

- The shelter does not involve materials that are toxic to humans, even when cut or modified for later reuse.
- The shelter does not involve materials that are toxic by burning or burying, and shall not pollute the ground water table or enter the food chain.

Color

- Military or camouflage colors are not to be used.

Buildability

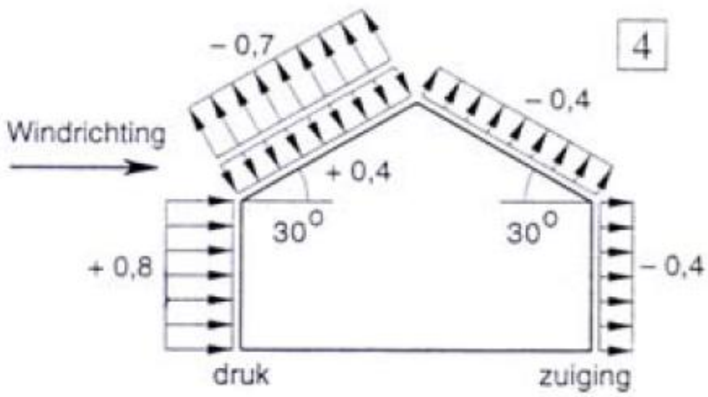
- The shelter can be distributed as a complete package, ready to put up, with all components included and all required tools.
- The frame is strong enough to support 6 to 8 30kg hanging live loads.

Appendix E
Wind Load Calculations

According to the requirements, the structure should be able to support the loads created by the weather plus the loads of a hard material composing the roof and the walls, e.g. wood. As the material to be used can't be precisely predicted, the example of wood and corrugated metal would be considered plus a security factor. (Forest Products Laboratory, 1999)

The load on the roof will be constituted by the weight of one person, the local material considered and the wind load. The weight of the structure is neglected as it is much lighter than the forces exhorting on it, however in the software simulation, full material properties were introduced in the model. The walls do not impose load on the structure as it is assumed they will be self supportive.

The method described was used on the reference material by: (van Kemenade, 2007)



Roof Area	19.44	m2
Lateral Wall Area	9.72	m2
Front Wall Area	7.01	m2

Formula To Calculate wind loads

F = A * Cpe * Pw

Pw = 0.7 kN/m2 * Dutch NEN 6702 norm for windy coast areas

	Area [m2]	Cpe +	Cpe -	Pw	Load [kN]	
Wind load Roof	9.72	0.4	-0.4	0.7	2.7216	-2.7216
Wind load Roof 2	9.72		-0.7	0.7	0	-4.7628
Walls, side wind	9.72	0.8	-0.4	0.7	5.4432	-2.7216
Walls, frontal wind	7.01	0.8		0.7	3.9256	0

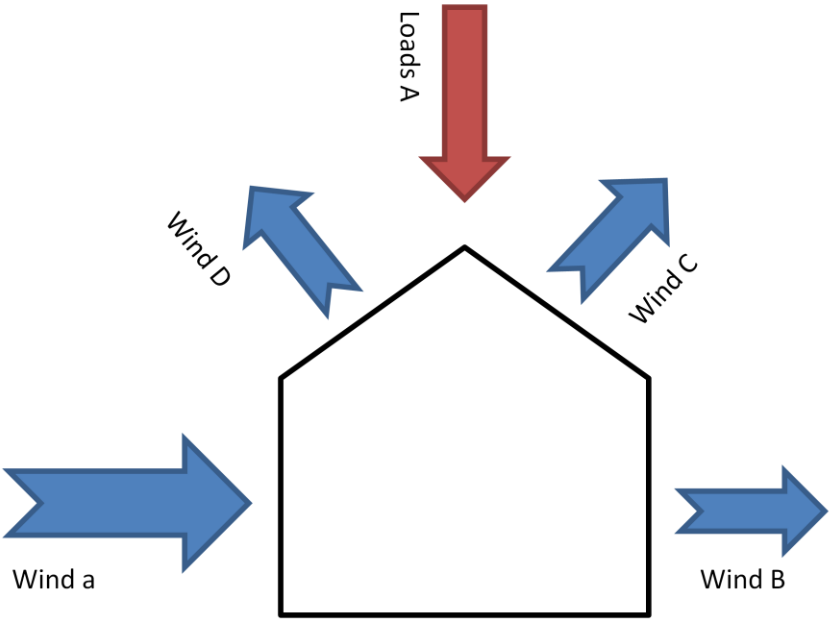
Roof materials loads

*Assuming dry pine wood which is considerably heavier than corrugated metal

Density of wood	560	kg/m3
Thickness	1	in
Load of roof	2712.61	N
Distributed Load	139.54	N/m2

Load of one person over the roof 80 kg

Resulting Loads



Loads on structure [kN]	
Load A	3.50
Wind A	5.44
Wind B	-2.72
Wind C	-2.72
Wind D	2.04

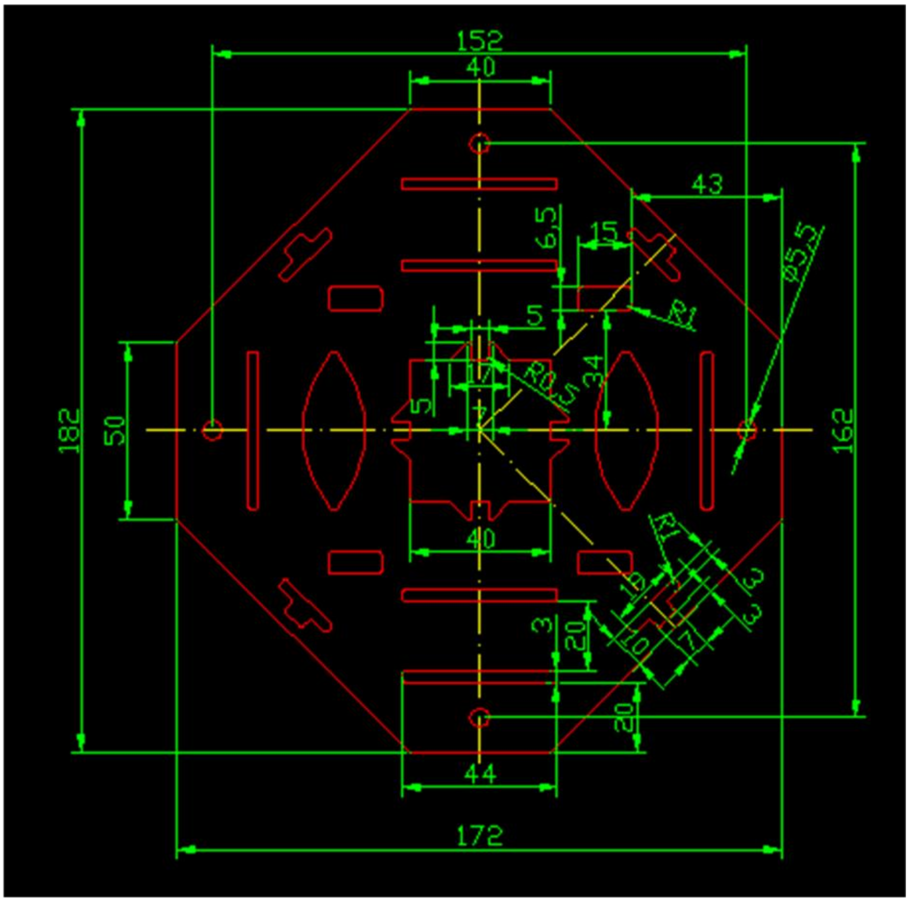
Distribution of forces over metallic structure			
Distributed Forces = Load / length			
Wall A		Roof C	
Fi	1.008	Fi	-0.504
Fo	0.504	Fo	-0.252
Wall B		Roof D	
Fi	-0.504	Fi	-0.378
Fo	-0.252	Fo	-0.189
* All data in [kN/m]			

Appendix F

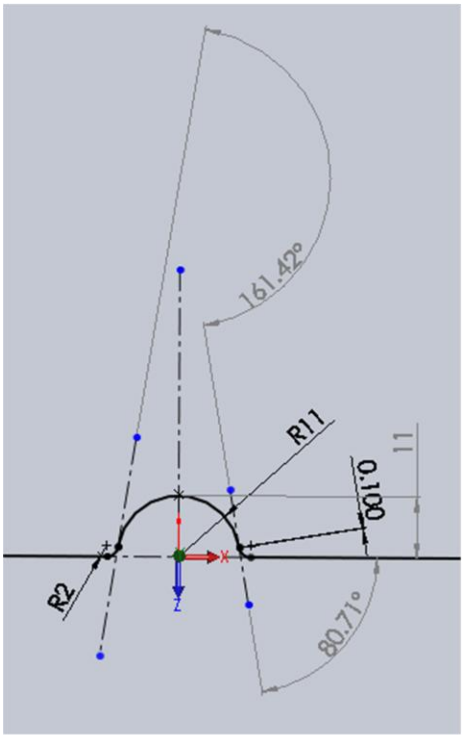
Manufacturing Observations

The following is a presentation of the observations made from my side after being entrusted to draw the 3D CAD of the manufacture plate after receiving the sketch base.

Original sketch base

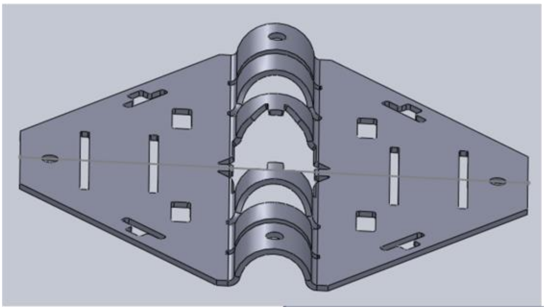


First sketch

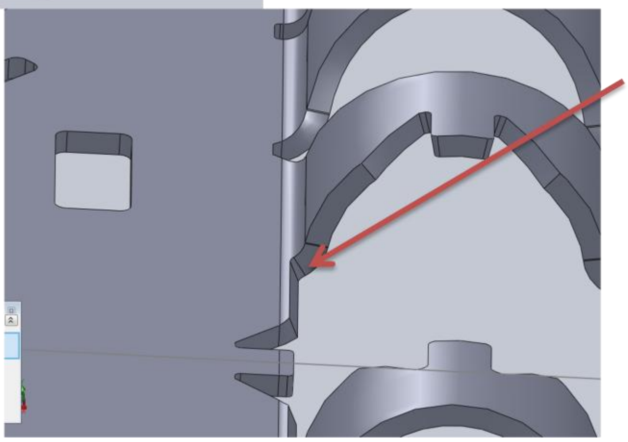


I start by creating the sketch that will guide the bending on the part. This ensures that all the radii are correct at the end.

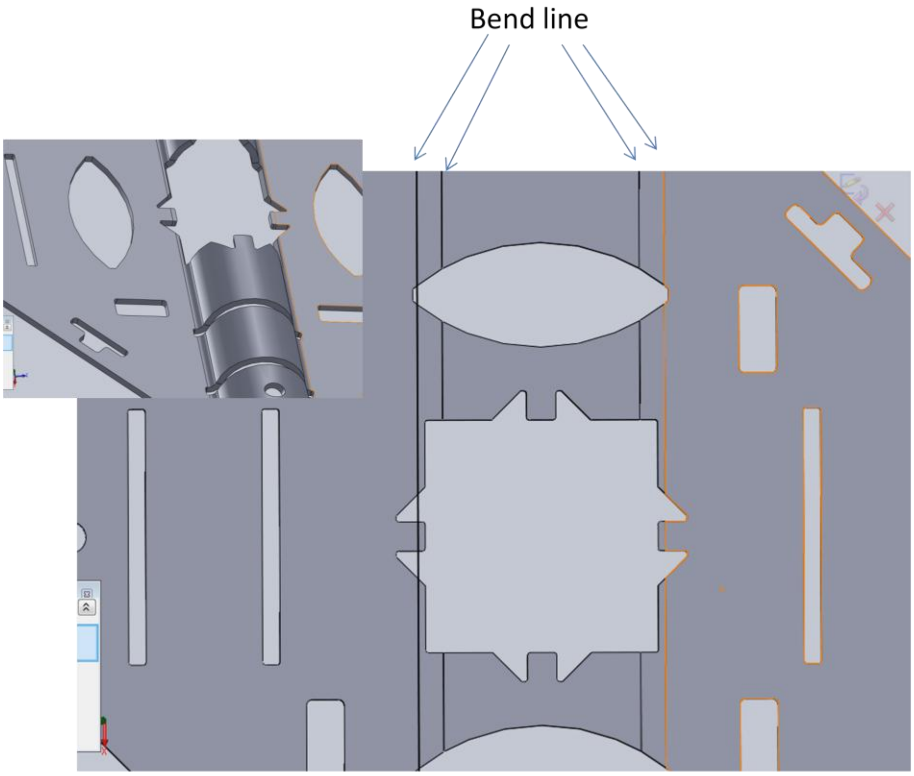
First bend



After trying the first bend, I noticed that the space needed for the part to bend is not enough.



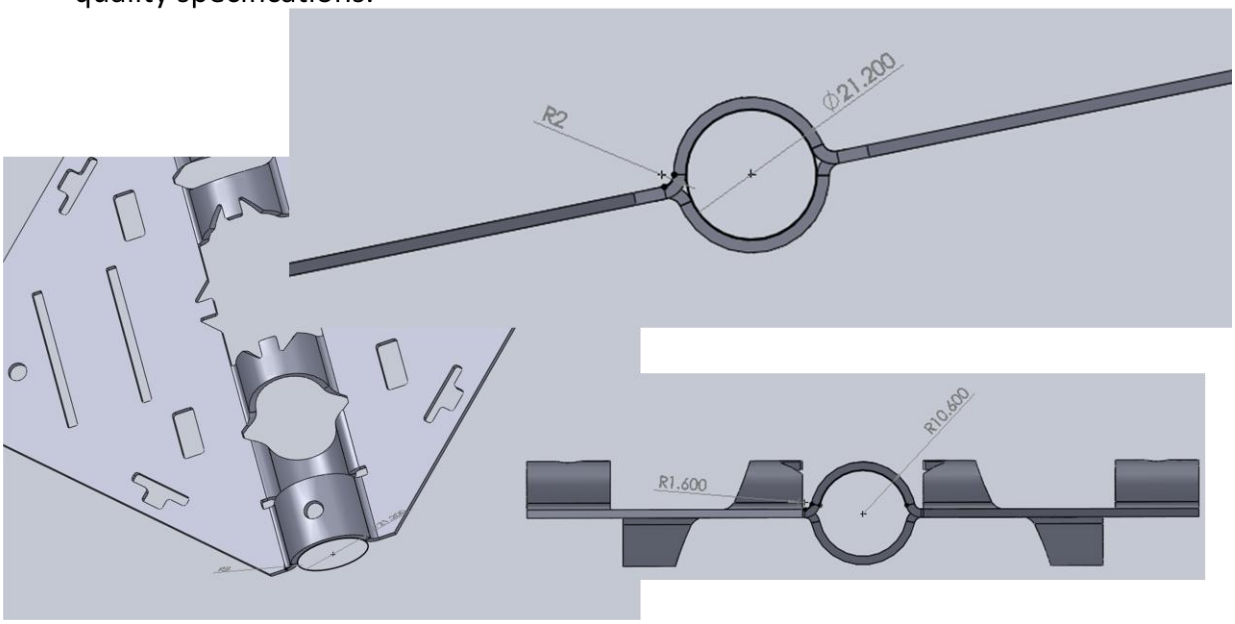
Overlapped bend



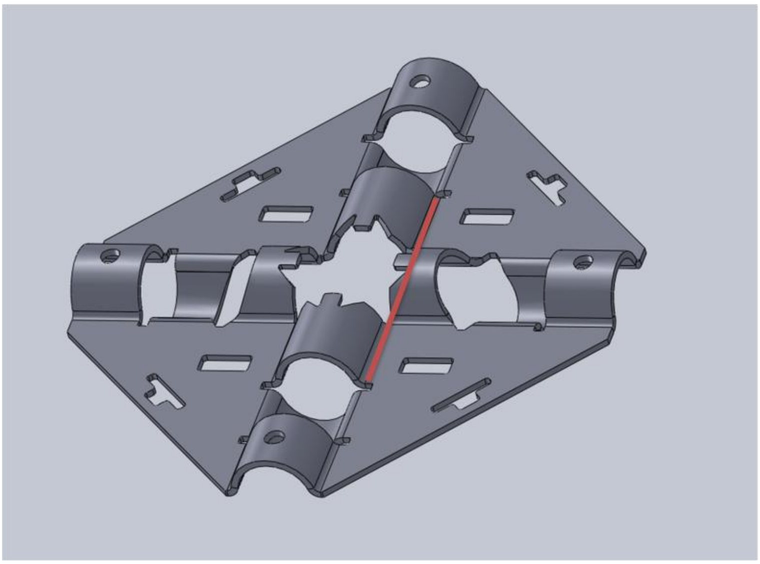
It is easy to notice that the elliptic cuts are longer than the square cut in the center.
I believe that in reality you can force the material to work, however controlling the quality of the overall part will be hard and there is a high risk of breaking it.

This detail is in both bends

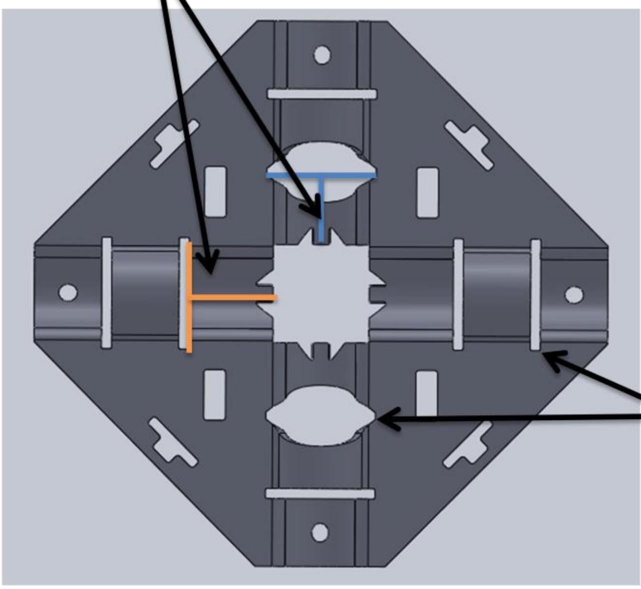
If you need this CAD only for illustration purposes and the dimensions are not important, I can modify the radii to make them “fit” the part. This will help you show the part around, but it will be hard to use for manufacturing control or quality specifications.



After the second step. I think the space for the last bending is very little. On CAD I just have to change the value of the angle, but I am sure that in bending the part will not be as easy to bend.

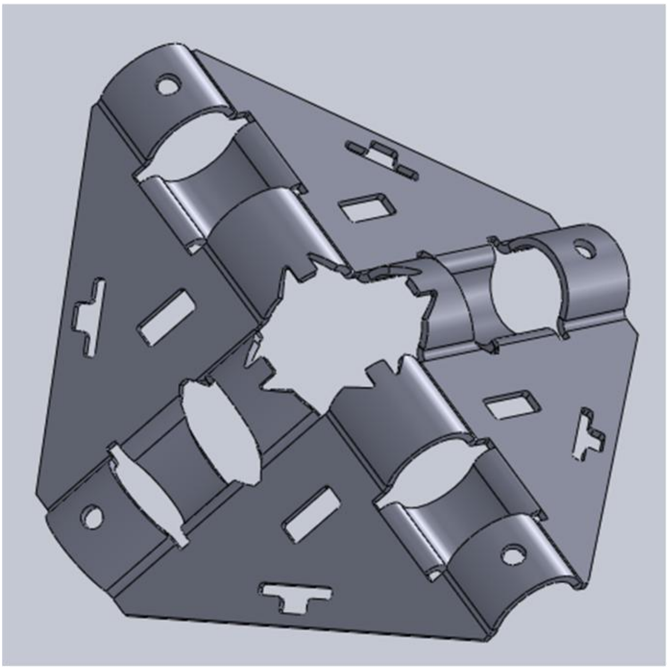


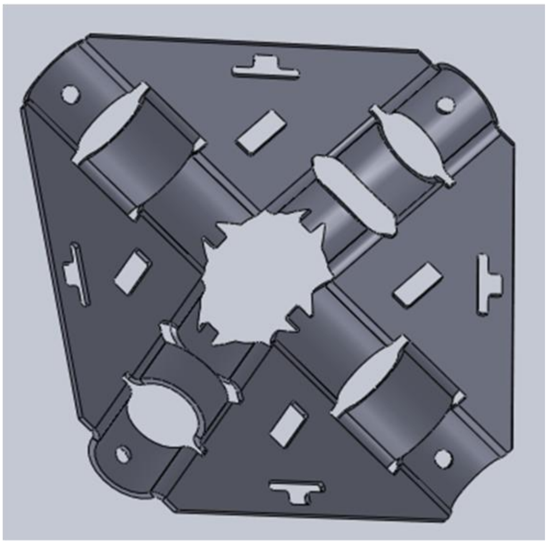
It is strange that this two distances are not the same



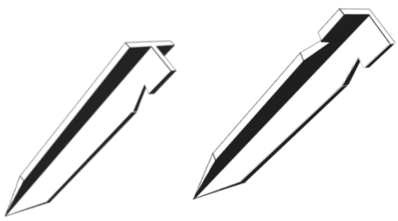
It would be a good idea to add fillets to this corners as they concentrate lots of efforts during the manufacturing process, it might crack.

This is how the final part looks like, I hope you are pleased.
If you need any further modifications, don’t hesitate to contact me.





Appendix G
Anchor Benchmark

Anchor benchmark comparison table	
	Rachet tite ™ Quick to install Secure anchoring in all soil conditions. Better in clay, hard packed or rocky soil. Permanent. Price 19.99 USD set of four. Aprox. 5 USD a piece. (ShelterLogic™, 2010)
	ShelterAuger™ Most versatile, Quick to install Secure solution for grass and unpacked soil conditions. Permanent or reusable Price: 20 USD set of four Aprox 5 USD a piece. (ShelterLogic™, 2010)
	ShelterSpike™ Provides secure tie-downs for canopies & pop ups. Ideal for any ground condition hard-packed soil, gravel or clay conditions. Permanent or reusable. (ShelterLogic™, 2010)
	T or V Pegs These are used for fixing guide ropes to the ground, The cheapest are generally T or V shaped for strength and up to 50 cm long of 2 mm thick steel. It is best if they are notched to hold the rope. Price: 15.95 USD for 5 Aprox. 3 USD per piece. (Ashmore, 2004b)

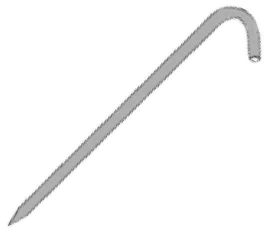
	Round pegs Easy access and manufacture Good for loose ground Temporal solution Poor quality round pegs are likely to bend Price 160 USD for bulk of 100 Aprox 1.6 USD per piece (Ashmore, 2004b)
	Hogan™ Auger Stake For applications requiring extra hold due to sand & loose soil conditions. 5/8 inch x 30 inch and 3/4 inch x 48 inch both with 4 inch double helix. Price: 14.45 USD (Hogan Company, Inc., 2005)

Table 17 Anchor benchmark

Appendix H
Design of Experiments for Structural Reinforcement Optimization

The following paper is done to analyze which reinforcement elements of the light frame structure for the emergency relief shelter are being utilized when a basic load is applied. This with the intention of optimizing the use of such elements by placing them in the most efficient place and avoid having elements that contribute little or nothing to the whole structure.

In the first stage of the design reinforcements consisted of a group of light weight sheet metal parts in the corners plus plastic braces in the sides to provide stability. It is the purpose of this analysis to evaluate the contribution each element is providing on individual basis to the overall stability of the structure.

It is important to mention that this is not a structural analysis with the intention to evaluate the safety of the tent, neither to evaluate if it will support the actual loads. The only purpose of this analysis is to find the optimal combination of the actual reinforcement elements. After this study, over the optimal case, a full structural study of the design and its parts will be conducted.

It must be mentioned that this section was made in two different parts, mainly because new information was generated during the first part that required new experimentation and a different evaluation method. In the first part, only one corner reinforcement was considered and the comparison criteria between different configurations was based only in the amount of parts and the reduction they provided to the displacement of the measuring point.

This method became useless when including the different corner reinforcements and when instead of using the full cross braces only one was used. In the second part, the evaluation is based on money, weight and relative reduction of the maximum displacement. Using this method it became easier to assess what configuration to use.

The first part however, is still explained in the thesis as the information withdrawn from it will help the reader understand the process the tent had during its development and the criteria that was used to evaluate the best solution. At the end, this process was made with the purpose of reducing cost and weight in accordance to the requirements stated at the beginning of the project.

The approach

As there is a virtually infinite combination of loads to which the structure might be subjected to in a real environment, a representative distributed force is going to be applied equally in all cases. The measuring point to determine the overall displacement of the parts will also be the same for all cases.

To organize the study and make the results easier to explain, each part has taken a different clear name depending on their position in the tent. This way the top level is A, the lower level is B and each section has a number.

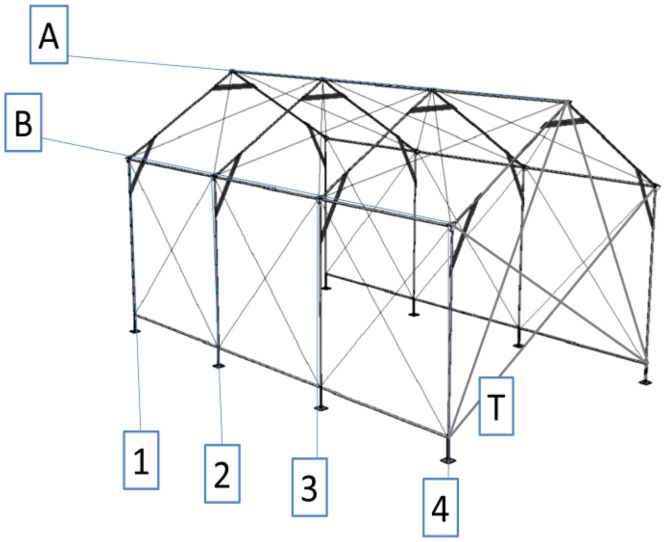


Figure 62 Names of reinforcement positioning system

Following the diagram it can be easily appreciated that most names represent an even number of elements to ensure that all possible solutions made from the combination of these elements is a symmetric solution. Also to differentiate between the different classes of reinforcements letters are used: R for the corner, T for the tension at the backside of the tent and C for the braces.

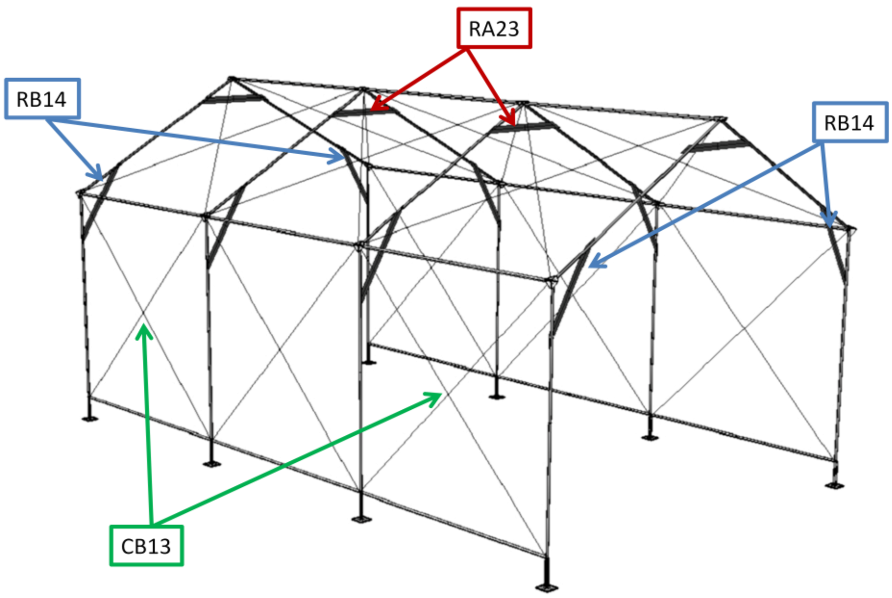


Figure 63 Reinforcement Naming example

DOE in a nutshell

The methodology to be used is called Design of Experiments. It is a commonly used powerful technique in the analysis of complicated production systems and sometimes in the mechanical optimization of complex parts. Its focus is to assign an “average contribution” of the independent parts to the final result through the minimum amount of experiments.

It consists in obtaining the difference between the average results of including or not a certain feature of value in the system. As the structural analysis of each possible combination of the tent would take a very long time to simulate, this approach would guide us in an efficient way to an optimal result.

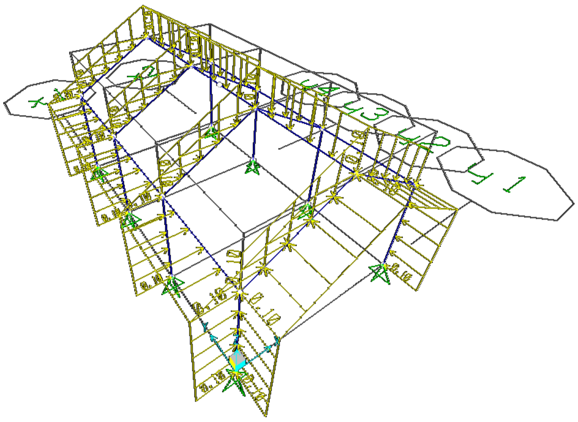


Figure 64 Testing loads distribution

Input forces

The input forces to run the analysis are meant to be representative of the three main directions in which forces will act upon the tent: lateral and frontal because of wind and vertical because of gravity and snow. The forces used in the analysis are also quite small compared to the real design parameters; however it was done this way to avoid that a certain combination of reinforcements couldn’t support the load and bucking effects would invalidate the computer analysis. As stated before, real load analyses would be performed after the optimal configuration is determined.

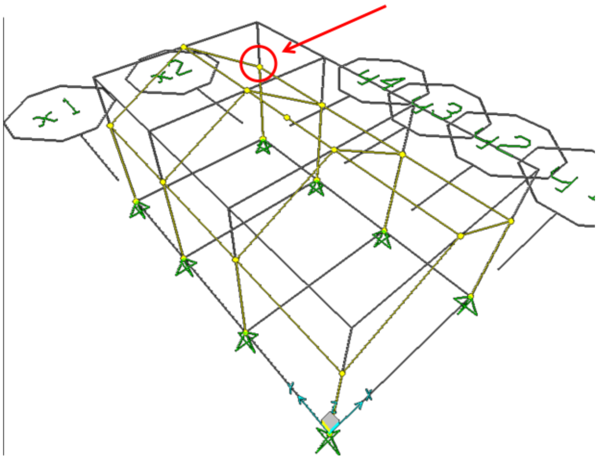


Figure 65 Original (wrong) measuring point

As is expected, different results can be measured from different parts of the structure. A sample point, constant in all configurations was chosen to be the evaluating parameter. At the beginning this point was placed on the absolute opposite corner of the input forces, but after a few runs of the experiment it was clear that a new point, a better representative, was needed.

Two control configurations were made to evaluate the results; one with all the reinforcements and one without any of them. With these two results, it was expected that the results of all other intermediate configurations should fall within the borders of the two initial runs.

The reason for changing from one point to the other was that a case produced a result outside of the boundary limits, implying that the effects caused by the input forces were being filtered by the intermediate structure and therefore the point first taken was not representative enough for measuring the output.

Test Run				
	Displacement			Resultant
	X	Y	Z	
Case 1	354.50	81.83	-0.02	363.82
Case 2	3.03	0.09	0.09	3.04
Case 3	157.56	116.79	-0.03	196.12
Case 4	-1.49	0.69	-0.06	1.64

Table 18 DOE test run

In Table 18 we can see the two first control cases one and two, then the third case with an expected outcome and then the fourth case which has a displacement resultant value under the second case which has no reinforcements. This is illogical as it implies that the reinforcements are actually diminishing the stability of the structure. What is actually happening here is that the effects of the forces are being filtered through the structure and thus they are not properly measured in the chosen point. It is also clear that the displacement in Z is very low compared to the other two displacements, a factor that is easily explained by the fact that being on the top of a vertical pole, the compression of the pipe has minimum values.

A new point was taken to represent the displacement and deformation of the tent. This time the point chosen was exactly in the middle of the tent where all three directions of the applied forces should inflict deformation hence making it easier to evaluate between different configurations. No filtering effect appeared in the following test rounds.

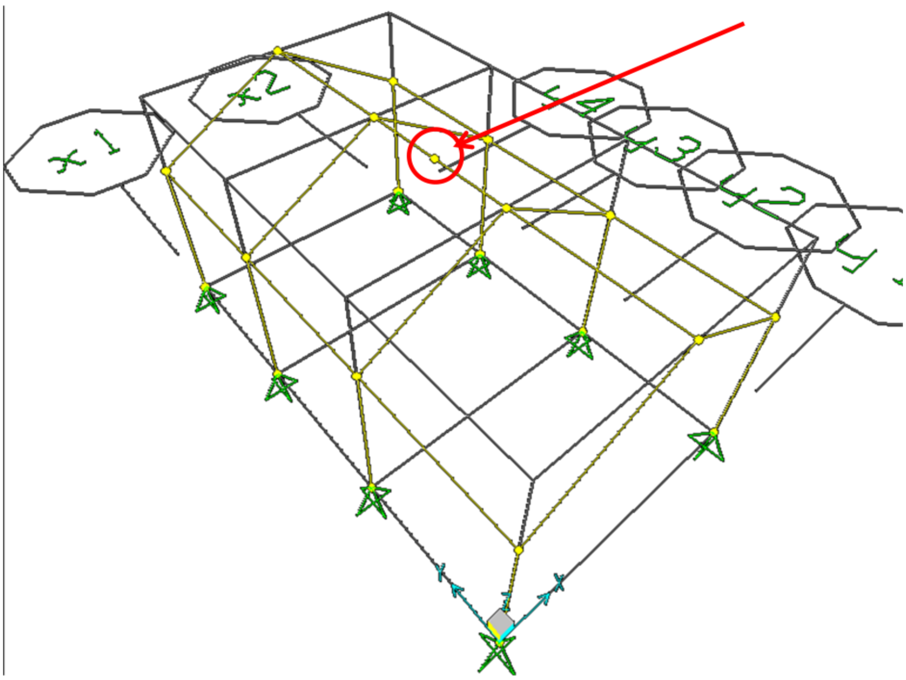


Figure 66DOE measuring point

The first run

The first run of experiments consisted of 8 different cases, including the two boundary first ones. Although most of the combinations tried to be random, some precaution was taken to ensure that a certain "engineering feeling" was present to get more relevant results. Such is the case of the back braces when it is pointless to test the two configurations together.

Table 19 First Run configurations

Case	CA13	CA2	CB13	CB2	RA14	RA23	RB14	RB23	TA	TB
1	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	1
3	1	0	0	0	1	0	1	0	1	0
4	0	1	1	1	1	1	0	1	1	0
5	1	1	0	1	0	1	1	0	0	1
6	0	1	1	1	0	1	0	0	1	0
7	1	0	0	0	1	0	0	1	0	1
8	0	0	1	0	0	0	1	1	0	1
AVERAGE EFFECT	**-59.23**	**-150.66**	**-117.37**	**-150.66**	**-31.83**	**-150.66**	**-83.45**	**-94.67**	**-54.53**	**-122.07**

Table 20 First Run displacement and resultants

Case	Displacement X	Y	Z	Resultant
1	353.71	95.70	-14.68	**366.72**
2	4.51	-2.48	-12.50	**13.52**
3	195.33	91.77	-38.60	**219.24**
4	80.35	-1.98	-15.12	**81.78**
5	25.12	-9.85	0.78	**27.00**
6	94.33	7.19	-19.55	**96.61**
7	125.63	66.08	-4.04	**142.00**
8	92.18	2.57	-15.80	**93.56**

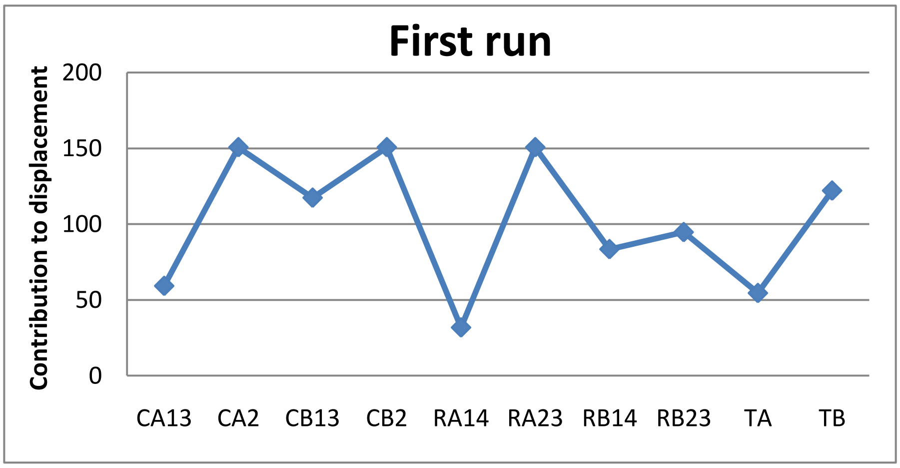


Figure 67 First run contribution to displacement

Even at this early stage, results clearly showed a tendency for the participation of some elements and at the same time the redundancy of others. Such is the case of the Reinforcements at the roof of the first and last section (RA14) which is not bringing much to the stability of the tent, while the reinforcements on the walls of the first and last section (RB14) does help considerably.

Second run

On the second run, the part with more relevance was left in its place and the one with less relevance was completely removed. This was done with the purpose of evaluating the rest of the reinforcements in a more detailed way.

Table 21 Second run configurations

Case	CA13	CA2	CB13	CB2	RA14	RA23	RB14	RB23	TA	TB
9	1	1	1	1	0	1	1	0	1	1
10	1	1	1	1	0	0	1	1	0	0
11	1	1	0	0	0	1	0	0	0	1
12	0	1	0	0	0	0	0	0	1	0
AVERAGE EFFECT	**-181.44**	**-**	**-134.04**	**-134.04**	**-**	**-114.37**	**-134.04**	**-28.94**	**23.74**	**-114.37**

Table 22 Second run Results

Displacement			**Resultant**
X	Y	Z	
4.51	-2.48	-12.50	**13.52**
103.01	0.76	-15.32	**104.15**
105.62	64.54	-2.95	**123.81**
245.49	87.91	-24.77	**261.93**

Adding these results to the previous ones a clearer pattern was formed between the elements. We can observe that two elements are very relevant, that the same reinforcements were not useful and that the rest are in the middle.

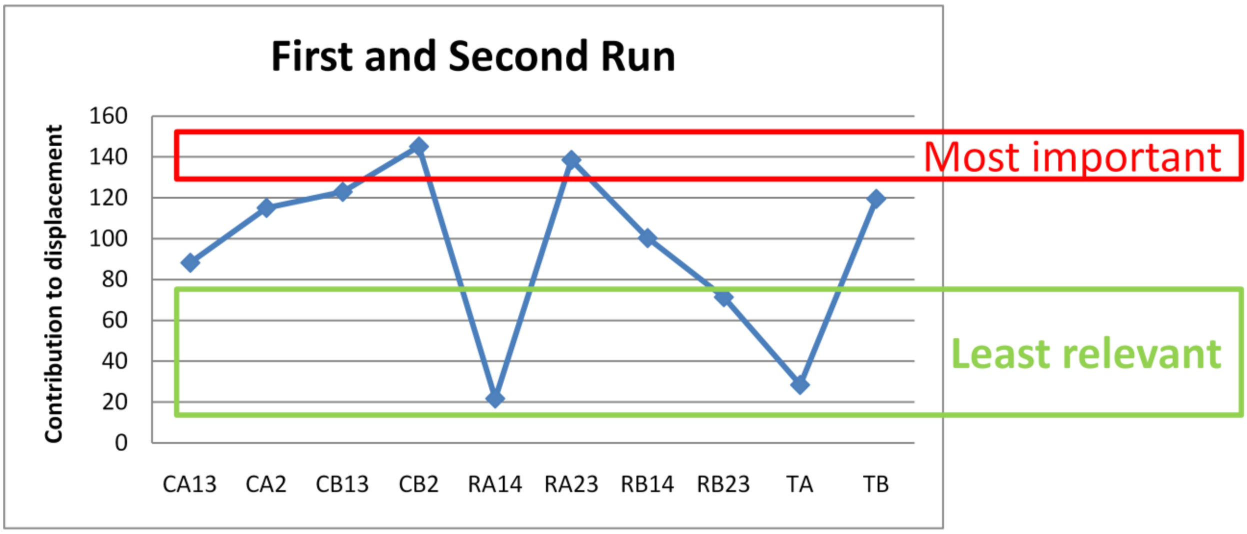


Figure 68 Most and least relevant reinforcements

Third run

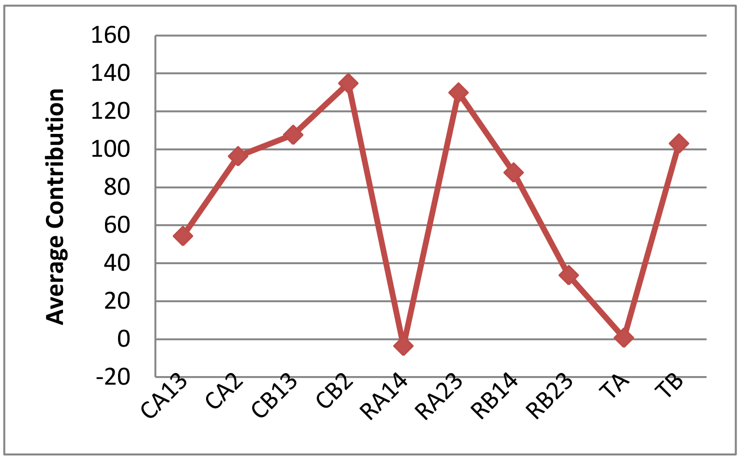


Figure 69 third run contribution

The third run had the purpose of determining the most optimal structure from the analyzed elements. Intermediate ranking reinforcements were validated to evaluate between the different combinations. It is important to mention that in a Design of Experiments approach, relationships between elements contribution is as important as each element contribution, however the relationships were not considered in this case because of the little outcome that could be drawn from it. amount of analysis it would need and the little outcome that could be drawn from it.

Table 23 Third run configurations

Case	CA13	CA2	CB13	CB2	RA14	RA23	RB14	RB23	TA	TB
1	0	0	0	0	0	0	0	0	0	0
2	1	1	1	1	1	1	1	1	1	1
3	1	0	0	0	1	0	1	0	1	0
4	0	1	1	1	1	1	0	1	1	0
5	1	1	0	1	0	1	1	0	0	1
6	0	1	1	1	0	1	0	0	1	0
7	1	0	0	0	1	0	0	1	0	1
8	0	0	1	0	0	0	1	1	0	1
9	1	1	1	1	0	1	1	0	1	1
10	1	1	1	1	0	0	1	1	0	0
11	1	1	0	0	0	1	0	0	0	1
12	0	1	0	0	0	0	0	0	1	0
13	0	1	1	1	0	1	1	0	0	1
14	1	1	1	1	0	1	1	0	0	1
15	0	1	1	1	0	1	0	0	0	1
16	0	1	0	1	0	1	1	0	0	1
17	0	0	1	1	0	1	1	0	0	1
AVERAGE EFFECT	**- 54.99**	**- 96.80**	**- 109.67**	**- 136.97**	**- 2.03**	**- 131.91**	**- 89.02**	**- 36.24**	**- 2.86**	**- 117.18**

The results were clear and four different combinations were considered to be the best candidates. To settle on a best design, new factors were introduced into the discussion. The first simulations were run under the idea that the pipes can rotate in all directions, but in reality there is a resistance to rotate. It also assumes that the pipes are fixed to the ground, however, because of the type of anchor to be used, which does not fix the pipes in the vertical position, the lateral braces need to be present as the whole structure relies on them to stay on ground in the case of a strong wind. In the structural analysis, to evaluate the safety of the tent, this will be taken into consideration by limiting the tension force of the pipes to cero.

Another parameter to be considered was the amount of elements to be used. A new value was calculated by dividing the amount of element by the total displacement of the measuring point. It is represented by the last column in the following table. Although this gives no real physical measure, it helps evaluate how efficient each member is working. It is important to try to minimize the number of elements in the tent, as the increased numbers will affect price, weight, volume and assembly time and complexity, therefore prices and total weight was estimated from each solution candidate and a final design was proposed

Table 24 element average contribution

			Displacement		Resultant		
Case	NO. elements	X	Y	Z			
1	0	353.71	95.70	-14.68	366.72	-	**0.00**
2	10	4.51	-2.48	-12.50	13.52	1.35	**0.74**
3	4	195.33	91.77	-38.60	219.24	54.81	**0.02**
4	7	80.35	-1.98	-15.12	81.78	11.68	**0.09**
5	6	25.12	-9.85	0.78	27.00	4.50	**0.22**
6	5	94.33	7.19	-19.55	96.61	19.32	**0.05**
7	4	125.63	66.08	-4.04	142.00	35.50	**0.03**
8	4	92.18	2.57	-15.80	93.56	23.39	**0.04**
9	8	4.51	-2.48	-12.50	13.52	1.69	**0.59**
10	6	103.01	0.76	-15.32	104.15	17.36	**0.06**
11	4	105.62	64.54	-2.95	123.81	30.95	**0.03**
12	2	245.49	87.91	-24.77	261.93	130.96	**0.01**
13	6	80.35	-1.98	-15.12	81.78	13.63	**0.07**
14	7	22.32	-10.14	0.67	24.52	3.50	**0.29**
15	5	80.35	-1.97	-15.11	81.78	16.36	**0.06**
16	5	97.68	-3.55	-15.24	98.93	19.79	**0.05**
17	5	81.53	2.92	-15.32	83.01	16.60	**0.06**

All of these considered we can observe in the new graph the performance on element efficiency of each individual design proposal.

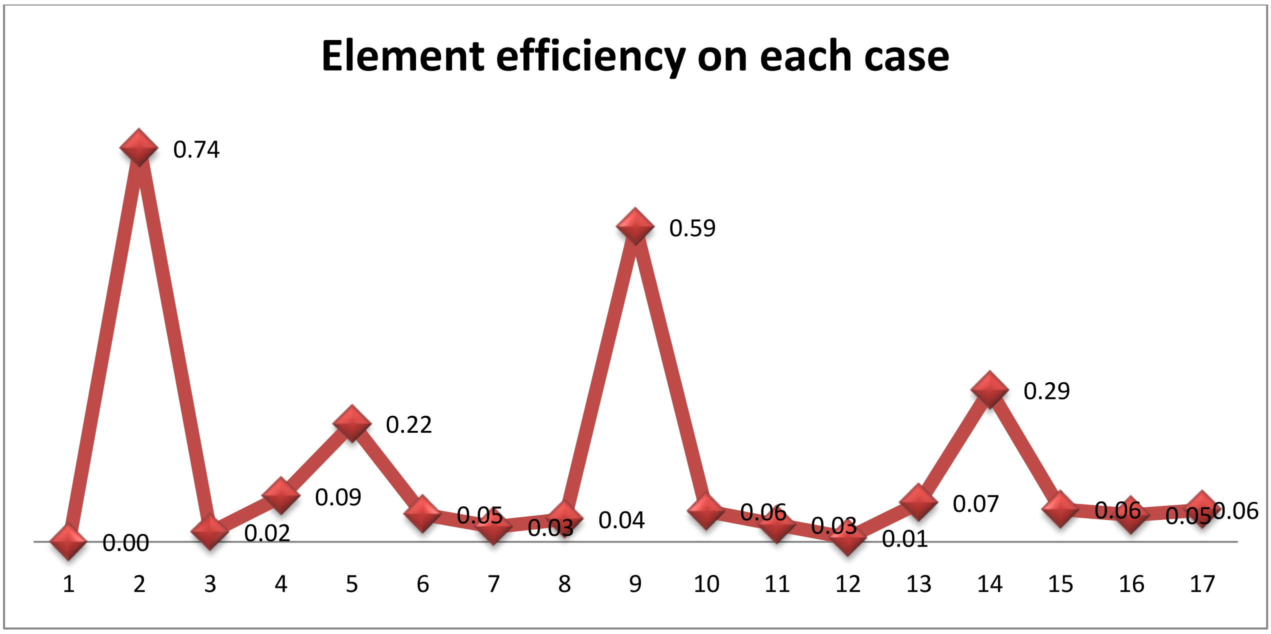


Figure 70 Element efficiency

From this plot we can notice there are four configurations which surpass the rest in its elements efficiency to reduce displacement. The element common to all these four configurations are the braces in the walls, therefore making them the most important element in the structure.

Case number two is the most efficient even if it is the control element involving all possible reinforcements. The second most efficient design is case number nine, which only differs from case number fourteen by the inclusion of tension element A. Case number five make a strong competition in the chart, but it does not include the braces CB13 which would help tighten the tent to the anchors and avoiding that wind lifts it from the air. For this reason it should be dismissed.

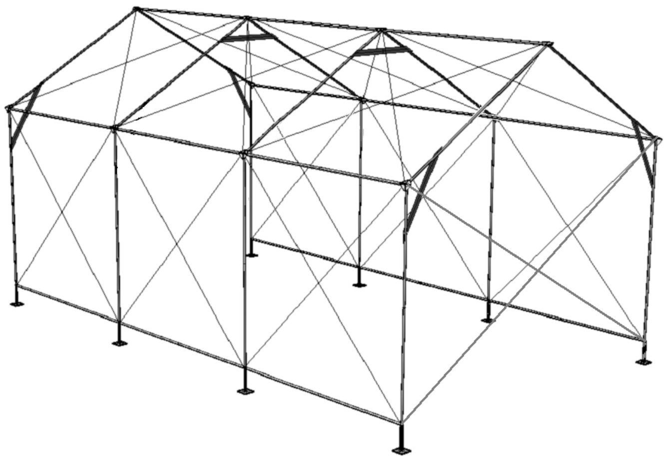


Figure 71 Configuration case 14

All this considered, case number fourteen is the best choice to go. It includes all the main components yet it remains economically a good case and more importantly it has fewer parts, reducing assembly time and complexity.

It is important to mention that the evaluation was made assuming rigid joints. In reality because of the sheet metal design of the actual joints, we know that an extra deflection is to be added in the joints adding value to the corner reinforcements. This was not done because the computing time to introduce such factor would have taken too long and would have been unnecessary to perform in all 18 different cases.

Conclusions

Through the Design of Experiments method it was possible to evaluate the interaction each individual member of the structure had on the overall stability. Eighteen different cases were evaluated and four principal solutions were found which at the time of corroborating them with other design requirements like price and time a final solution was presented as the most suitable.

An overall 13% reduction in projected costs and 21% reduction in weight was achieved by this method. Also, after the results obtained from this study, a limited amount of configurations will be evaluated to pass the security norms that are demanded by the international help organizations, speeding up the evaluation period to move to the prototype stage of the project.

Recalculating the price and weight

With this new information a new analysis of price and weight was done to compare the results and evaluate the improvement of the design. The following information is based on the document "Light weight structure" (Karlsson, 2009), we can see that although the reduction in reinforcements does help to reduce weight, complexity and price, it is the large structural elements like the pipes and joints that bring most of the weight and cost. Therefore, although there is an improvement in these areas, is complexity and time of assembly that has really progressed.

Table 25 Original price and weight

Price on Specification Sheet

			Weight U/T (kg)		Price U/T (SEK)	
BOM	DIM (mm)	# of Units	Unit	Total	Unit	Total
1. HTS Tube	1800x22x0.8	31	0.75	23.25	12.51	387.81
2. HTS Joint	170x170x1	12	0.2	2.4	3.2	38.4
3. HTS Ground Pin	300x50x1	16	0.12	1.92	1.92	30.72
4. HTS Anchor Plate	100x100x1	8	0.08	0.64	1.28	10.24
5. HTS Roof Truss	170x150x1	12	0.4	4.8	6.4	76.8
6. Galvanization	-	-			0.5 / Kg	12.65
7. Packaging straps	3500x13x0.5	24	0.01	0.24	0.1 / m	8.4
8. Strap braces	-	24	0.01	0.24	0.2	4.8
9. Pack & Assembly	-	1		2		50
TOTAL				**35.49**		**619.82**

Table 26 Price and weight of case 14

Case 14						
			Weight U/T (kg)		Price U/T (SEK)	
BOM	DIM (mm)	# of Units	Unit	Total	Unit	Total
1. HTS Tube	1800x22x0.8	22	0.75	16.50	12.51	275.22
2. HTS Joint	170x170x1	12	0.20	2.40	3.20	38.40
3. HTS Ground Pin	300x50x1	0	0.12	0.00	1.92	0.00
4. HTS Anchor	380 x 76	6	0.58	3.50	16.00	96.00
5. HTS Roof Truss	170x150x1	8	0.40	3.20	6.40	51.20
6. Galvanization	-	-			0.5 / Kg	12.65
7. Packaging straps	3500x13x0.5	24	0.01	0.24	0.1 / m	8.40
8. Strap braces	-	24	0.01	0.24	0.20	4.80
9. Pack & Assembly	-	1		2.00		50.00
TOTAL				**28.08**		**536.67**

Structural elements review Part 2

The results from the previous analysis were presented to a group of architects involved in other areas of the same project and to the stakeholders. From this a rain of ideas was generated and new parts, configurations and anchoring systems were introduced into consideration. Also the comparison characteristics and the evaluation method, to determine which one was to be the optimal solution, were refined.

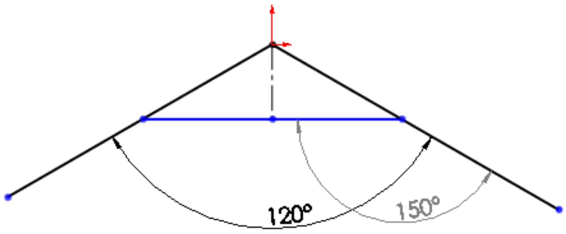


Figure 72 Joint Angles

The simulations showed that in every cross member not both cables were working efficiently. So only using one could provide a very similar outcome while reducing the amount of parts.

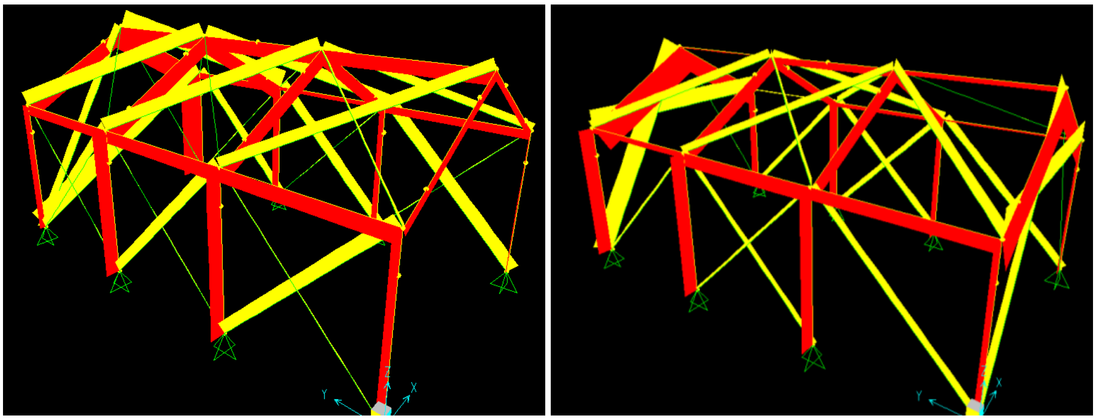


Table 27 Axial forces in different configurations

A new idea that came from the architects was to place the door in a lateral side instead of the ends of the tent. Such change would allow putting reinforcement bracings on both sides of the tent, thus improving the stability of the overall structure considerably. This modification demanded a new study to determine how the tent would behave in the absence of a section's lateral reinforcements however it looked very promising plus it open several possibilities at the moment of arranging several tents in a camp.

Besides the position of the door and the addition of the reinforcements on the side where it was previously located, new elements were introduced and with them their usage configurations. One idea was to replace the metal sheet corner reinforcements with pipes of the same length as the ones used for the rest of the structure. This solution could demand designing a new part to position it or using the already used joints with some modifications. However, before the experiment phase, one could predict that the stability should be increased.

This new configuration would also demand a new tool. Although the general joint could be modified, when thinking on a large scale production, a new tool would be needed to give the joint an angle of 150 degrees instead of the originally designed 120. At this moment the joints were considered to be done in several steps as is explained later and only the last stage of bending would be affected by this change.

Considering the half braces and the new elements introduced, the amount of configurations to be tested, at least virtually, incremented dramatically. This demanded for a new organized way of displaying the information, especially to transmit it to the rest of the people involved. What is most important is to mention that through the experiment, combinations were made based on the results of the previous run. This way an element that proved to contribute largely to the diminishing of the output displacement would be more present through the different tests than an element that does not contribute as much.

The new results included only values of displacement given a same input of force through the structure. In order to compare between each different configuration and element, considering the great variety of parts available a common comparison measure was created. In the first run, an efficiency factor was obtained by dividing the amount of parts by the displacement obtained, however this proved to be of little help as the amount of parts is not so relevant to the success of the product.

Based on the initial requirements, weight and cost are of the outmost important, and so the comparison between different options should be based on these two.

Evaluating the first proposed configuration from the document "light weight structure" from emergency housing for refugees which can be found in the appendix the importance of each part both in weight and cost were obvious.

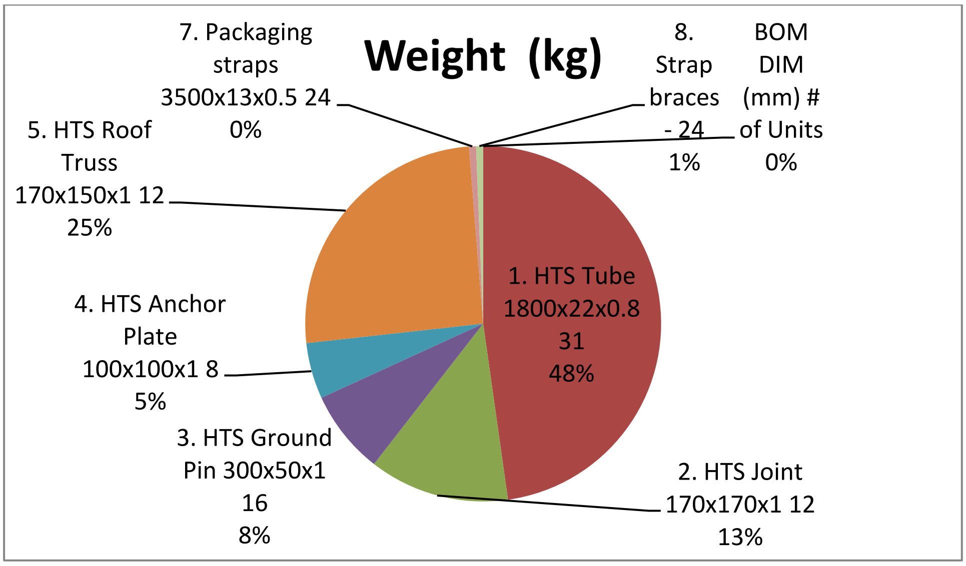


Figure 73 Weight distribution in tent

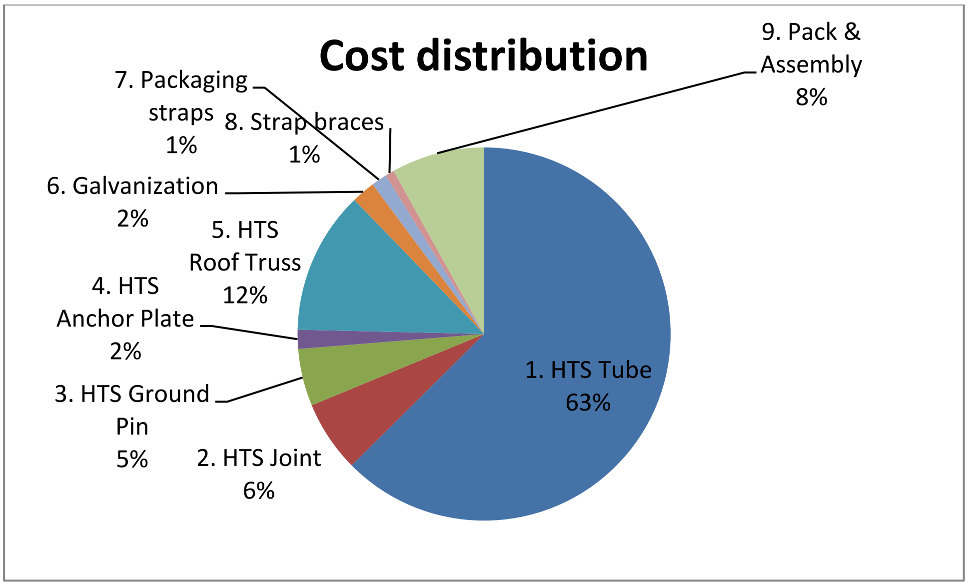


Figure 74 Cost distribution in tent

As it is obviously seen, it is the pipes that have the most relevance in the weight and the cost contribution to the product. It is important to mention that for the cost is only considered that of production. Storage, transport and maintenance costs cannot be included as they vary considerably depending on the place of use. The joints and reinforcements would probably have a tooling development cost which is not considered in the individual cost of production of the tents. However considering the large amount of parts that shall be produced to cover the demand, is logical to not include the tooling production cost in this analysis.

Now that the cost and the weight are to be the new parameters for comparing different configurations of the tent, all configurations tested until now, were calculated to compare them between each other. The displacement as a comparing measure was also redefined. Instead of measuring the displacement in millimeters it is measured in percentage reduced (relative reduction).

In other words, a measurement of the total displacement of the tent having all possible reinforcements was made, and then another one was done having no reinforcements at all. Now each configuration will be measured in what percentage of the total displacement was reduced. It makes more sense to compare this way as the real inputs to which the tent will be subjected to, are not fixed but random. In this case, we can see how much of this displacement will be prevented by adding certain group of reinforcements. It also has the ability of making it easy to compare when having to use different inputs and to measure different outputs as it would be explained later in the project when doing the security testing.

In Figure 75 you can see how each configuration is represented by three bars, one includes the relative reduction of the maximum displacement given a certain input, the second bar represents the added weight to the structure by the reinforcement parts and the third bar represents the total cost of only the reinforcements parts of that certain configuration without the weight of the basic structure which is common to all cases. There is a larger image in Appendix K next to the detailed table with configurations.

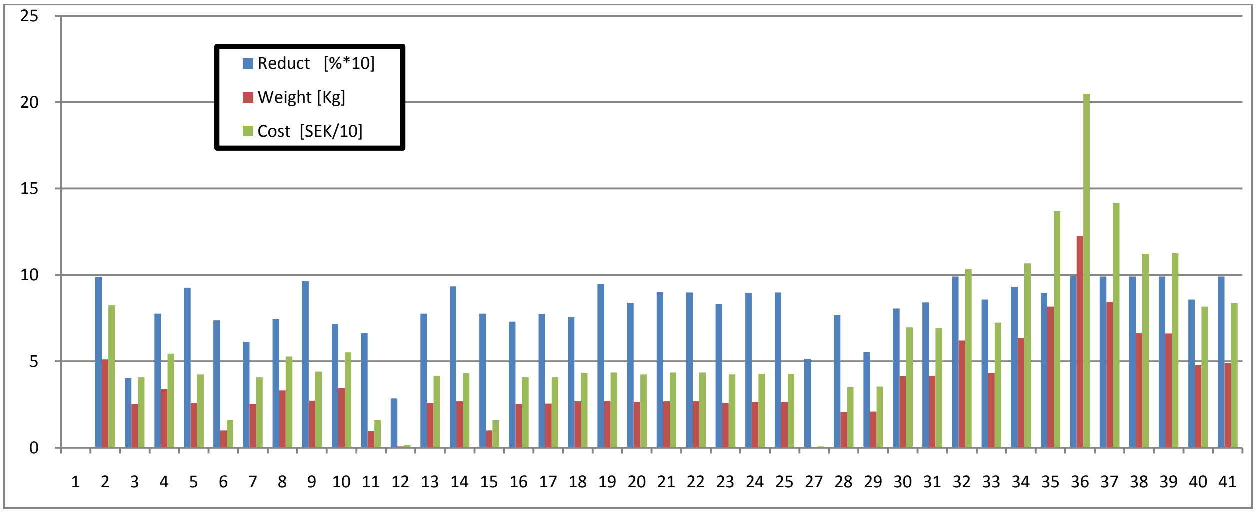


Figure 75 Case data

Several things were not practical to include in the virtual analysis. Things like the different ground anchoring properties, tolerance and dimensional variation, rotational movement of the poles, etc. All of these were purposely disregarded as the complexity they would add to the analysis and the increased simulation time would not make up for the results they could give. However, being aware of the differences between the virtual simulation and the real usage conditions, a physical experiment was conducted to test the hypothesis made by the virtual analysis results. The virtual results worked like a map, letting us know which configurations might be the most successful ones and thus reducing dramatically the time needed for testing the different options.

It was also important to get a feeling of how stable the tent was. As much as we could establish a certain deformation parameter, the way the whole tent felt by the force applied by a human hand could influence the acceptance of the product in the camps and by the organizations.

Appendix I
Physical Testing

Once the initial mapping for testing was planned a space was arranged with the help of Triple Steelix, a small factory in Borlänge where the initial prototypes were built and the tests were to be conducted. Anchoring systems were installed in the floor to fasten the pipes. The space also presented the possibility to pull forces from it in several directions.

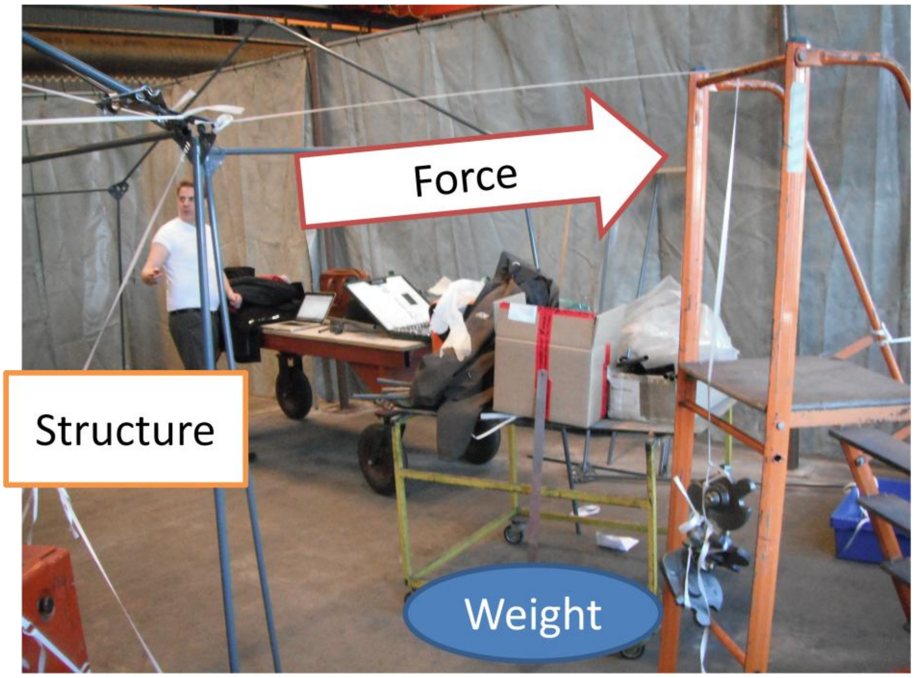


Figure 76 tent test layout

The experiment consisted in applying a common load to different reinforcement configurations to evaluate the output displacement from this input. At the moment I arrived, however, the tent was already assembled and special fasteners were used that would prevent me from disassembling, eliminating the capacity to include all possible configurations. This caused the purpose of the experiment to change from testing the best configurations shown in Table 24 to testing the individual participation in the reduction of displacement. A change that made this physical experiment very similar to the one performed virtually. The results were then compared to results obtained from the same configurations but in a virtual experiment.

Table 28 Physical test results

Case	PA14	PA23	CA13	CA2	CB13	CB2	TC	TA	initial measure	weight measure	displacement
42	0	1	0	1	0	1	1	0	760	773	13
43	0	0	1	1	1	1	1	0	782	785	3
44	1	1	0	0	1	1	1	0	780	789	9
45	1	1	0	0	0	1	1	0	780	794	14
46	1	1	1	1	1	1	1	0	785	790	5
47	0	1	0	0	1	1	0	1	780	824	44
48	0	0	0	0	0	0	0	0	752	825	73
49	1	1	1	1	1	1	0	1	783	789	6
50	1	1	0	0	0	0	0	1	780	810	30
51	1	1	0	0	0	0	1	0	780	808	28

These results can only be compared with the virtual simulations if we use the approach previously explained of obtaining the percentage of displacement reduction. Considering this, a comparison between the measured results and the actual virtual simulation was performed.

Table 29 Comparison between physical and virtual experiments

Case	simulation	AV red	test	AV red2	Difference
42	58.24	84%	13	82%	2%
43	6.08	98%	3	96%	2%
44	54.63	85%	9	88%	-3%
45	57.86	84%	14	81%	3%
46	6.06	98%	5	93%	5%
47	28.22	92%	44	40%	53%
48	366.42	0%	73	0%	0%
49	28.22	92%	6	92%	1%
50	119.07	68%	30	59%	9%
51	99.16	73%	28	62%	11%

Comparing with simulated results we can see a rough relationship between both results, except for case 47, the difference between each measurement could be explained by the difference in the type of anchoring and the flexibility of some of the internal members.

The next step is to decide upon a certain group of different configurations to apply the forces needed by the requirements. With this in mind, five different configurations were selected. Besides the best options, two extra cases were selected to use as extreme cases and create a final comparative margin to judge and select between options. These two control cases are number zero which has no reinforcements at all and is already working as a maximum displacement case and number two. It is also important to evaluate what would happen if the tent is disassembled or wrongly assembled on site. Case zero provides feedback as a worst case scenario where all reinforcements were lost or removed. Case two is the second control item; it includes all possible reinforcements made of stamped parts. This case is working to evaluate a best case which shall be close to optimum in resisting the environment forces.

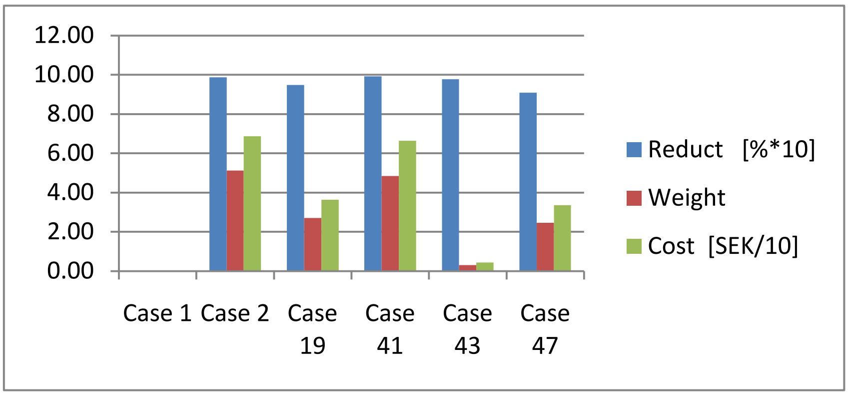


Figure 77 Final configurations

The final 5 cases were chosen because of their capacity to be built and efficiency in weight and cost compared to the reduction of instability. It is also important to mention that through this research cycle, new knowledge was generated and considered for the final run. For example, after the proposal for the new position of the door was presented, it became clear that structurally it was a considerable advantage. Taking this in consideration, cases 2, 14 and 19 will now be reconfigured to include this modification.

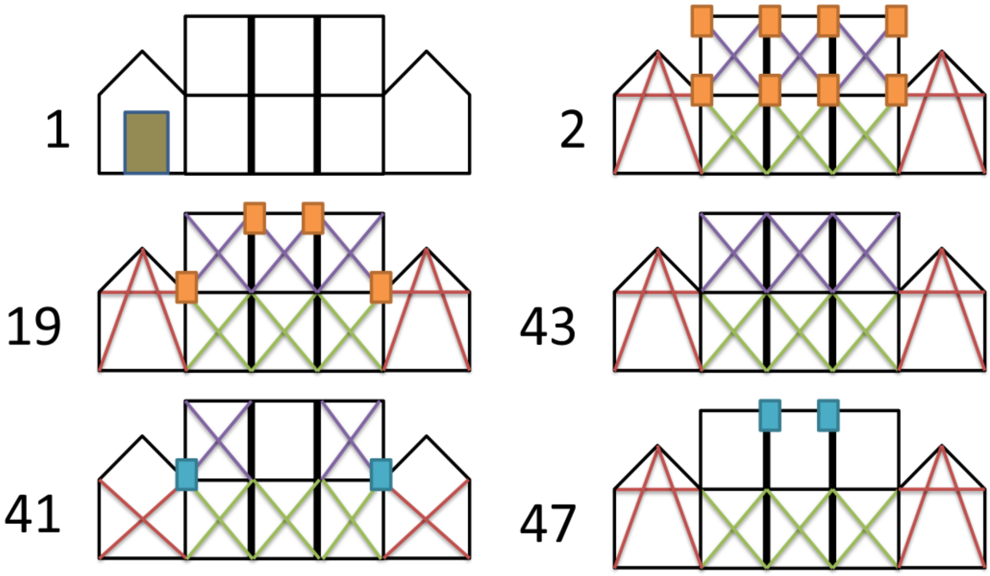
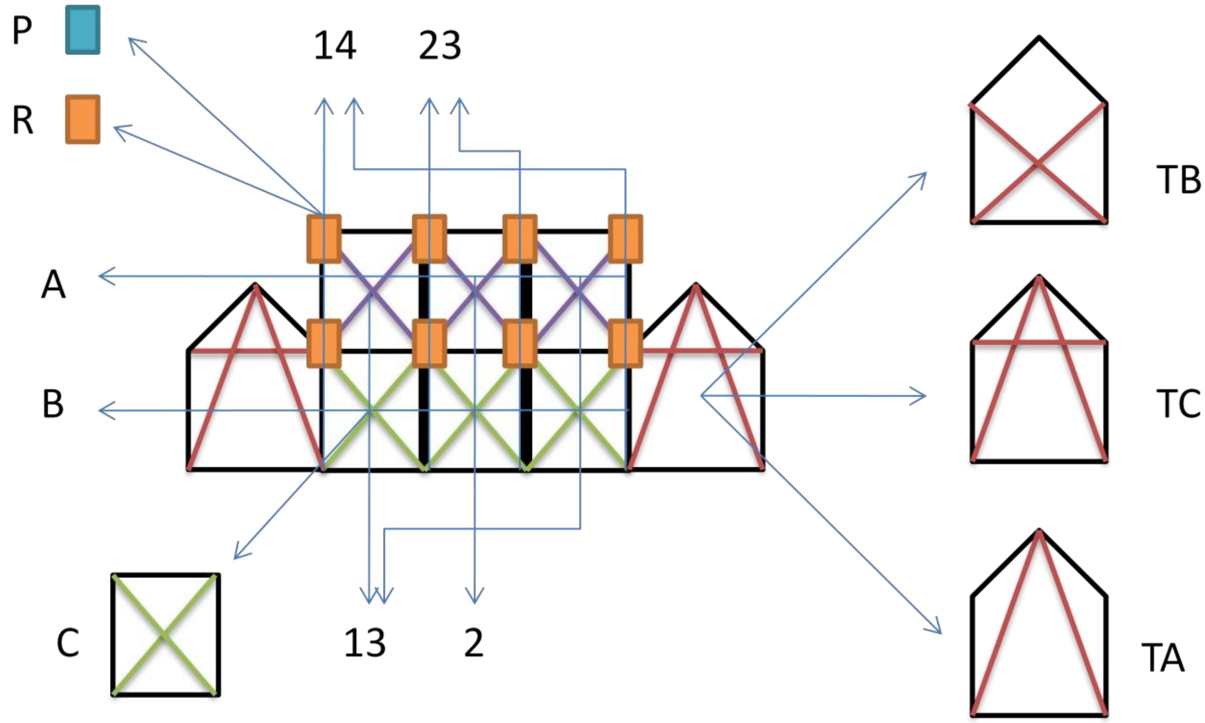
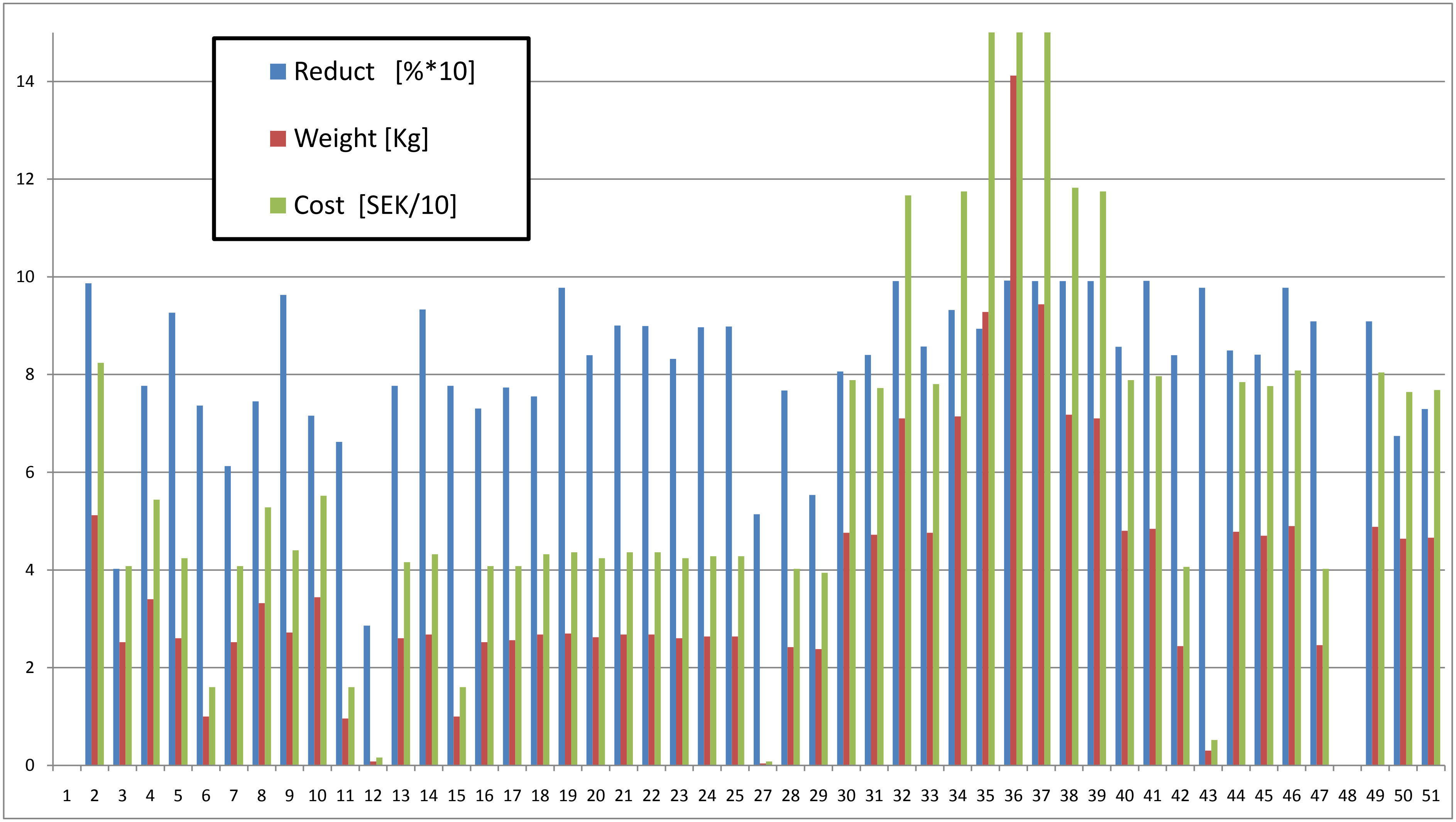


Figure 78 Best configurations

Appendix J
Naming System for Design of Experiments



Appendix K Qualitative Comparison



Case	CA13	CA2	CB13	CB2	RA14	RA23	RB14	RB23	PA14	PA23	PB14	PB23	TA	TB	TC	No elements	displacement					
weight	0.08	0.04	0.08	0.04	0.8	0.8	1.6	1.6	2.3	2.3	4.6	4.6	0.04	0.04	0.06							
Price	1.6	0.8	0.8	0.8	12.8	12.8	25.6	25.6	37.82	37.82	75.64	75.64	0.8	0.8	1.2			Reduce %	Weight [Kg]	Cost SEK	Reduce [%*10]	Cost [SEK/10]
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	366.72	0%	0	0	0.00	0.00
2	1	1	1	1	1	1	1	1	0	0	0	0	1	1	0	10	4.88	99%	5.12	82.4	9.87	8.24
3	1	0	0	0	1	0	1	0	0	0	0	0	1	0	0	4	219.24	40%	2.52	40.8	4.02	4.08
4	0	1	1	1	1	1	0	1	0	0	0	0	1	0	0	7	81.78	78%	3.4	54.4	7.77	5.44
5	1	1	0	1	0	1	1	0	0	0	0	0	0	1	0	6	27.00	93%	2.6	42.4	9.26	4.24
6	0	1	1	1	0	1	0	0	0	0	0	0	1	0	0	5	96.61	74%	1	16	7.37	1.60
7	1	0	0	0	1	0	0	1	0	0	0	0	0	1	0	4	142.00	61%	2.52	40.8	6.13	4.08
8	0	0	1	0	0	0	1	1	0	0	0	0	0	1	0	4	93.56	74%	3.32	52.8	7.45	5.28
9	1	1	1	1	0	1	1	0	0	0	0	0	1	1	0	8	13.52	96%	2.72	44	9.63	4.40
10	1	1	1	1	0	0	1	1	0	0	0	0	0	0	0	6	104.15	72%	3.44	55.2	7.16	5.52
11	1	1	0	0	0	1	0	0	0	0	0	0	0	1	0	4	123.81	66%	0.96	16	6.62	1.60
12	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2	261.93	29%	0.08	1.6	2.86	0.16
13	0	1	1	1	0	1	1	0	0	0	0	0	0	1	0	6	81.78	78%	2.6	41.6	7.77	4.16
14	1	1	1	1	0	1	1	0	0	0	0	0	0	1	0	7	24.52	93%	2.68	43.2	9.33	4.32
15	0	1	1	1	0	1	0	0	0	0	0	0	0	1	0	5	81.78	78%	1	16	7.77	1.60
16	0	1	0	1	0	1	1	0	0	0	0	0	0	1	0	5	98.93	73%	2.52	40.8	7.30	4.08
17	0	0	1	1	0	1	1	0	0	0	0	0	0	1	0	5	83.01	77%	2.56	40.8	7.74	4.08
18	1	1	1	1	0	1	1	0	0	0	0	0	1	0	0	7	89.75	76%	2.68	43.2	7.55	4.32
19	1	1	1	1	0	1	1	0	0	0	0	0	0	0	1	7	8.18	98%	2.7	43.6	9.78	4.36
20	0.5	1	0.5	1	0	1	1	0	0	0	0	0	0	0	1	6	58.87	84%	2.62	42.4	8.39	4.24
21	0.5	1	0.5	1	0	1	1	0	0	0	0	0	0	0	2	7	36.57	90%	2.68	43.6	9.00	4.36
22	0.5	1	0.5	1	0	1	1	0	0	0	0	0	0	0	2	7	36.93	90%	2.68	43.6	8.99	4.36
23	0	1	0	1	0	1	1	0	0	0	0	0	0	0	2	6	61.51	83%	2.6	42.4	8.32	4.24
24	0.5	0	0.5	1	0	1	1	0	0	0	0	0	0	0	2	6	37.78	90%	2.64	42.8	8.97	4.28
25	0.5	0	0.5	1	0	1	1	0	0	0	0	0	0	0	2	6	37.38	90%	2.64	42.8	8.98	4.28
27	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	178.14	51%	0.04	0.8	5.14	0.08

28	1	0	0	0	0	0	0	0	1	0	0	0	1	0	0	3	85.38	77%	2.42	40.22	7.67	4.02
29	0	1	0	0	0	0	0	0	0	1	0	0	1	0	0	3	163.84	55%	2.38	39.42	5.53	3.94
30	1	1	0	0	0	0	0	0	1	1	0	0	0	1	0	5	71.00	81%	4.76	78.84	8.06	7.88
31	0	0	1	0	0	0	0	0	0	0	1	0	0	1	0	3	58.66	84%	4.72	77.24	8.40	7.72
32	1	0	1	0	0	0	0	0	0	1	1	0	0	1	0	5	3.23	99%	7.1	116.66	9.91	11.67
33	0	1	1	0	0	0	0	0	0	0	0	1	1	0	0	4	52.26	86%	4.76	78.04	8.57	7.80
34	1	1	1	0	0	0	0	0	1	0	0	1	1	0	0	6	24.81	93%	7.14	117.46	9.32	11.75
35	0	0	0	1	0	0	0	0	0	0	1	1	1	0	0	4	38.93	89%	9.28	152.88	8.94	15.29
36	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	10	2.90	99%	14.12	232.52	9.92	23.25
37	1	0	1	1	0	0	0	0	0	0	1	1	0	1	0	6	3.15	99%	9.44	155.28	9.91	15.53
38	1	1	1	1	0	0	0	0	0	1	1	0	0	1	0	7	3.20	99%	7.18	118.26	9.91	11.83
39	1	1	0	1	0	0	0	0	0	1	1	0	0	1	0	6	3.22	99%	7.1	117.46	9.91	11.75
40	0	1	1	1	0	0	0	0	1	1	0	0	0	1	0	6	52.54	86%	4.8	78.84	8.57	7.88
41	1	0	1	1	0	0	0	0	0	0	1	0	0	1	0	5	2.95	99%	4.84	79.64	9.92	7.96
42	0	1	0	1	0	0	0	0	0	1	0	0	0	0	1	4	58.80	84%	2.44	40.62	8.40	4.06
43	1	1	1	1	0	0	0	0	0	0	0	0	0	0	1	5	8.23	98%	0.3	5.2	9.78	0.52
44	0	0	1	1	0	0	0	0	1	1	0	0	0	0	1	5	55.21	85%	4.78	78.44	8.49	7.84
45	0	0	0	1	0	0	0	0	1	1	0	0	0	0	1	4	58.42	84%	4.7	77.64	8.41	7.76
46	1	1	1	1	0	0	0	0	1	1	0	0	0	0	1	7	8.11	98%	4.9	80.84	9.78	8.08
47	0	0	1	1	0	0	0	0	0	1	0	0	1	0	0	4	33.40	91%	2.46	40.22	9.09	4.02
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	367.02	0%	0	0	-0.01	0.00
49	1	1	1	1	0	0	0	0	1	1	0	0	1	0	0	7	33.40	91%	4.88	80.44	9.09	8.04
50	0	0	0	0	0	0	0	0	1	1	0	0	1	0	0	3	119.38	67%	4.64	76.44	6.74	7.64
51	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	3	99.16	73%	4.66	76.84	7.30	7.68