ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

FAST, CHEAP & ADAPTABLE: A DIGITAL MODEL FOR DESIGNING TEMPORARY POST-DISASTER HOUSING

M.Sc. THESIS

Amina REZOUG

Department of Informatics

Architectural Design Computing Program

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İSTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

HIZLI, UCUZ ve UYARLANABİLİR: AFET SONRASI GEÇİCİ KONUT TASARIMI İÇİN DİJİTAL BİR MODEL

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Amina REZOUG, a **M.Sc.** student of ITU **Institute of / Graduate School of Architecture** student ID **523101001**, successfully defended the **thesis/dissertation** entitled "FAST, CHEAP & ADAPTABLE: A DIGITAL MODEL FOR DESIGNING TEMPORARY POST DISASTER HOUSING", which she prepared after fulfilling the requirements specified in the associated legislations, before the jury whose signatures are below.

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To my parents,

FOREWORD

I am deeply grateful to the following people for their support and inspiration.

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Amina REZOUG

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ABBREVIATIONS

CNC	**:** Computer Numerical Controlled
CAD	**:** Computer Aided Design
CAM	**:** Computer Automated Manufacturing
BIM	**:** Building Information Modeling
SIP	**:** Structural Insulated Panels
OSB	**:** Oriented Strand Board

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FAST, CHEAP & ADAPTABLE: A DIGITAL MODEL FOR DESIGNING TEMPORARY POST-DISASTER HOUSING

SUMMARY

Shelter is one of the first needs that emerge after natural or technological disasters. Post-disaster shelter designs need to address climatic conditions, evacuees' psychology, social factors and long-term usage, without missing the necessity of fast and cheap production. This thesis proposes a design model for a specific stage of post disaster recovery in order to improve the quality of shelters.

Temporary housing responds to a transitional period in which evacuees get back to a functioning daily life. In the time of disaster, recovery focuses on meeting basic needs such as medical treatment, food, shelter and basic services. However long term recovery planning requires the consideration of temporary settlements and housing construction. Since digital tools hold potential for simplification, standardization and modularization, they can be applied to this humanitarian design problem to achieve a better performance and mass-customization.

This thesis proposes a digital model that generates customized, habitable prefabricated living units for temporary post-disaster housing. The proposal is a model for the existing prefabrication systems and aims fast, adaptable and low-cost generation of temporary houses for post disaster evacuees. It computes varying designs responding to different cases of post disaster situations, to minimize the cost and time required for variety. The thesis approaches the problem by dividing it into manageable pieces and using parametric modeling tools to solve specific problems that interconnect.

This thesis is comprised of two different parts. The first part, chapters 1 and 2, gives the reader brief historical contexts to general post disaster strategies and prefabrication from around the world converging to the practice in Turkey. The second part of the thesis, chapters 3 to 5, explains the proposed model as a fast and state of the art alternative to the existing temporary housing.

HIZLI, UCUZ & UYARLANABİLİR: AFET SONRASI GEÇİCİ KONUT TASARIMINDA DİJİTAL BİR MODEL

ÖZET

Barınma, dünyada ve ülkemizde doğal afetler sonrası ihtiyaçlar arasında ilk sıralarda gelmektedir. Bu ihtiyaca cevap verecek tasarımların, hem iklim şartlarına, afetzede psikolojisine, sosyal ilişkilere ve uzun süreli kullanıma uygun olması, hem de hızlı ve ucuza üretilmesi gerekmektedir. Barınma ihtiyacının aşamalı olarak ele alındığı afet sonrası süreçlerde üretilen çözümlerin kalıcı olduğu gözlenmiştir. Afetzedeler geçici olarak yerleştirildikleri barınaklarda yıllar boyunca yaşamaktadırlar. Bu barınakların afetzedelerin fiziksel ve sosyal ihtiyacını karşılamaya yeterli olmadıkları genel bir kanıdır. Bu bağlamda hep kalıcı olarak iş gören geçici ve kalıcı çözümlerin getirdiği harcamaların gereksiz tekrarını en aza indirmek de önemlidir. Bu çalışmada önerilen, bir seferde hızlı ve uzun vadede gelişebilir nitelikte barınak üretimine, bilgisayar destekli bir mimari çözümdür.

Afet sonrası barınakların hızlı üretiminde ekonomik kriterler, tektipleşme ve sosyal girdiler barınak tasarımının özelleşmesinin detaylı olarak ele alınamamasına yol açmış, bu durumlar özellikle uzun vadede kullanımı devam eden barınak gruplarında sorunlar üretmiştir. Afet sonrası barınak ihtiyacının karşılanması için, yer seçimi başta olmak üzere, sosyolojik verilere, çevresel etkenlere ve maddi olanaklara stratejik planlama ile yaklaşmak önemlidir. Afet sonrası barınak tasarımı kriterlerini psikolojik ve sosyolojik açıdan değerlendiren çalışmalar, afetzedelerin sosyal ve ekonomik yaşantılarının kapsayıcı ve katılımcı süreçlerle yeniden düzenlenmesi gerektiğini ortaya koymaktadır. Son yıllarda sayısal yöntemlerle desteklenmiş tasarım süreçleri alana bu yönde katkı koyabilmektedir. Mimarlık alanındaki bazı örneklerde parametrik tasarım destek sistemleri kullanılarak afet sonrası ucuz barınak projelerinde tektipleşmeye alternatif, çeşitlilik barındıran ama az ve vasıfsız işgücüyle, bu durumda afetzedelerin katılımı, ile üretilen çözümler önerilmiştir.

Toplumumuzda afet sonrası barınma çözümlerinde sayısal teknolojilerden daha etkin bir biçimde yararlanılabilir. Önerilen çalışma, afet barınağı problemine sayısal teknoloji ve tasarım boyutunda katkı koymayı amaçlamaktadır. Afet bölgesine ve sosyo-ekonomik düzeylere göre çeşitlilik ve uyarlanabilirlik barındıran bu çözümde, üretim maliyetini arttıracak yeni bir sistem tasarımı yerine, Türkiye'de yaygın kullanımı olan bir prefabrik yapı sisteminin, parametrize edilmiş birleşim profil detayları üretimi ve farklı panel kesimleri ile zenginleştirilerek uyarlanması için gerekli olan araştırma sunulmaktadır.

Afet sonrasında afetzedelerin barınma ihtiyacını karşılayacak, farklı aşamalarda farklı aciliyetlere cevap verecek çözümleri dört aşamada tanımlanmıştır. Afetzedelerin barınma ihtiyacının karşılanmasında izlenen aşamaları şöyle belirtilmiştir: acil barınma, geçici barınma, geçici konut ve kalıcı konut. Bu çalışmanın odaklandığı aşama geçici konut aşamasıdır.Bu aşamada afetzedelerin yeni kalıcı konutlarına geçmeden önce, planlanan veya öngörülenden daha uzun bir süre barındıkları geçici konutlar, afetzedelerin günlük eylemlerini ve sorumluluklarını yerine getirmeleri için yetersizdir. Tanımlanan kullanım sürelerini geçmesi veya konut yaşamıyla ilgili gereksinimlerin karşılanmaması durumunda afetzedelerin stres ve hoşnutsuzluk seviyeleri artış gözlemlenmektedir. Bu nedenle, ülkemizde kullanım süresi belli olmayan ve planlanandan çok daha uzun süre kullanılan geçici konut problemine alternatif çözümler aranmaktadır.

Afet sonrası barınaklar, daha kalıcı, dönüştürülebilir malzemelerden oluşan, sökülüp veya taşınıp tekrardan kullanılabilen yapılar olmalıdır. Afetzedelere hizmet edecek olan bu barınakların, kendi kendine yetebilen birimler olması önem taşımaktadır.

Türkiye'de herhangi bir afet durumunda ülkenin her yerine aynı tip prefabrik evler gönderilmektedir. Oysa, farklı coğrafi bölgelerin farklı ihtiyaçları ve çevresel faktörleri söz konusudur. Afetzedelerin konforu, sosyal ve psikolojik travmalarını atlatmaları, sağlıklı birer birey olarak hayatlarına devam etmeleri için büyük önem taşımaktadır. Dolayısıyla tasarımdaki çeşitlilik ve uyarlanabilirlik önem kazanmaktadır. Geçmişteki afetler için geliştirilen barınak örneklerine bakarsak, hızlı üretime verilen önceliğin ve ekonomik kısıtların, çeşitliliğe olanak vermediğini görürüz. Bu bağlamda gelişen dijital teknolojilerinin ve parametrik tasarım araçlarının kullanımı ile hızlı üretilen ve bir araya getirilen kitlesel bireyselleştirilmiş tasarımlar oluşturmak mümkündür.
Kitlesel bireyselleştirme, uygun fiyatlara yüksek kalitede ev tasarımlarına olanak vermektedir. Burada kalite kullanıcıların ihtiyaçlarını karşılamakla ölçülmektedir. Farklı durumlar için farklı tasarımlar geliştirmek geleneksel yöntemlerle fazla zaman ve enerji gerektirirken, bilgisayar destekli tasarım ve üretim süreçleri sayesinde bireylere özel tasarımlar geliştirmek, eskisi kadar külfetli değildir. Afetzedelerin aile yapıları, kişi sayıları, kültürel alışkanlıkları gibi özellikler göz önünde bulundurulmadan aynı tip prefabriklere yerleştirilen kullanıcının ihtiyaçları göz ardı edilmektedir. Kaliteli, geçici konutların üretilmesi ve tasarlanması için bilgisayar destekli tasarım araçları ve üretim teknolojileri büyük önem taşımaktadır. Sayısal teknolojilerin sağladıkları olanaklardan yararlanarak, Türkiye'de afet sonrası barınma problemine daha özelleştirilmiş, geliştirilmiş ve kaliteli çözümler üretilebileceği savunulmaktadır. Çalışmamızın amacı, geçici barınak sorununu, sayısal teknoloji ve tasarım boyutuyla ele almaktır.
Tez iki parçadan oluşur. Tezin ilk kısımı, okuyucuya prefabik ve afet sonrası stratejileri hakkında dünya'da ve Türkiye'deki örneklerden kısa bir tarihçe sunar ve 1 ve 2 numaralı bölümleri kapsar. Tezin ikinci kısmı ise mevcut afet sonrası durumlarını değerlendirerek bu problemlere çözüm oluştuabilecek bir modelin nasıl geliştirilebileceğini anlatır ve 3, 4 ve 5 numaralı bölümleri içerir.
İlk bölüm çalışmaya alt yapı hazırlamak ve ikinci bölüme bir giriş hazırlamak üzere geliştirilmiştir.
İkinci bölüm afet sonrası konut çalışmalarının kısa bir tarihçesini sunmaktadır. Bu bölüm afet sonrası yeniden yapılanma sürecindeki aşamalardan, geçici konut yapım aşamasına odaklanmıştır. Afet sonrası yeniden yapılanma aşamaları ve geçici konut ve barınak terimleri bu çalışma kapsamında tanımlanmıştır. Karşılıklı yardım ve kendi kendine yardım kavramları sorgulanmakta ve bu projeye nasıl dahil olabileceği sorgulanmaktadır. Son olarak parametrik modellemede ve dijital üretimin afet sonrasında nasıl katkı koyabileceği tartışılmaktadır. Bu çalışmada, afetzedelerin kendi kalacakları konutların yapımında rol almaları, yıkılan çevrenin yeniden kurulmasının birer parçası olmaları, yeni hayatlarındaki geçici de olsa belli bir süre barınacakları konutların ihtiyaçlarına göre şekillenmesi ve bu travmatik sürecin daha kolay atlatılmasının sağlanması gerekliliği açıklanmıştır.
Üçüncü bölüm prefabrik üretim teknolojilerini tanıtıp, bu çalışma kapsamındaki malzeme kullanımı hakkında bilgi vermektedir. Bu çalışmanın ele alacağı bir başka konu ise geçici konutları oluşturan, temel tasarım birimlerini bir araya getiren, temel yapı elemanlarının tasarımı ve üretimidir. Çelik profillerin ve sandeviç panellerin üretim süreçleri anlatılmaktadır. Bunların ötesinde üretim sürecinin ve işçiliğin bu projedeki önemi tartışılmaktadır.
Dördüncü bölümde ise geliştirilen model detaylı bir şekilde anlatılmaktadır. Afet durumunda ilk anda ortaya çıkan ucuz ve hızlı barınma ihtiyacına sosyal ve ekonomik düzeylerde çeşitlilik ve uyarlanabilirlik içeren çözüm önerisi geliştirilmesi

için prefabrik yapı sistemi irdelenerek, bu sistemi zenginleştirebilecek parametreler ile öneriler için bir üst çerçeve sunulmaktadır. Ana tasarım kararları ve kullanıcı arayüzleri tanımlanmaktadır. Kullanılan programlar ve geliştirilen programın parametreleri açıklanmıştır. Son olarak yapılan çalışmadan geliştirilen maket hakkında bilgi verilmektedir.

Son bölümde ise tasarlanan modelin hangi yönlerden eksik kaldığı ve ileri dönük potansiyel çalışmalar üzerinde durulmuştur. Belirlenen hedeflere ne ölçüde ulaşıldığı belirlenmiştir. Önerinin geliştirilmesi için öneriler ortaya konmuştur ve yapılan çalışmanın önemine değinilerek tez tamamlanmıştır.

1. POST DISASTER SHELTER DESIGN

Shelter is one of the major needs that arise after natural or man-made disasters. Within this study, the definition of shelter is narrowed down to a living space inhabited by disaster victims who lost their homes and are in need of one for an uncertain amount of time. The time of habitation in post-disaster shelters is assumed to be short, however this is not always the case. Due to the uncertainty in the duration of the use of these shelters, habitants often find themselves living in impersonal spaces. It is essential to develop a design that takes into consideration the cultural, geographic and climatic factors. It is also necessary that the design adapts to long-term use, and gets fabricated and constructed at low cost in a short period of time. The aim of this thesis is to develop a parametric model for fast produced post-disaster shelter.

Post-disaster housing is as broad a topic as housing policies and applications. The United Nations Disaster Relief Coordinator defines it as meeting the urgent, temporary and permanent sheltering needs of the disaster survivors (1982). Varying housing and sheltering solutions are provided at different stages of post disaster. Quarantelli (1995) classifies the post disaster recovery stages into four: emergency sheltering, temporary sheltering, temporary housing and permanent housing. This thesis focuses on temporary housing as it covers the transitional period in which evacuees try to function in daily routines. This is the stage where design aspect and customization is needed the most.

Housing and sheltering plays a significant role in the psychological state and social relations of disaster victims. In Turkey, it has been witnessed that the use of temporary housing extends to many years and exceed the expected time of use (Şener & Altun, 2009). Since temporary housing is the initial threshold to the recovery process where victims start getting back to their daily lives as active individuals of the society, the time spent there has a major effect on the victims’ psychology and their social life.

The design of post disaster houses in accordance with the inhabitants changing needs and traditions that depends to their regional environment is mainly dependent on the design decisions (Enginöz & Ünlü, 2006). The cultural and traditional background is an essential input that defines the size and layout of the house. For example, families in Eastern societies tend to live together. The crowding in one household comes with different space requirements and life routines different than any typical Western nuclear family. The thesis aims to incorporate these factors into a digital model that will bridge design criteria and production.

Identical shelters are insufficient in responding to the varying people's social and physical needs. Familial and social values in a society show variance as well as daily routines of individuals. For example, kitchen habits can be quite diverse. Some families live and eat in the kitchen while others separate in space use their daily activities. Similarly, practices of privacy control may change from one family to another, influence the use of interior partitions, and space organization. Conservative families for instance would prefer to separate their daughter and son's bedrooms. Large families would definitely need more space and different plan layouts than nuclear families. All these requirements are not extreme requests to realize, and it is possible to integrate these requirements into the design process in order to fulfill diverse needs. The diversity needs to be provided to these families in order to help them feel at home and recover from their trauma while rebuilding their home culture.

Displaced families inhabit temporary houses for a significant amount of time until they move into their renovated or newly built permanent houses. In this period of time, they make changes and adaptations as much as they can to improve the place they dwell. However if adaptability is provided and basic requirements are fulfilled evacuees will need to make fewer modifications since the house design will meet their needs. Examples of modification done by evacuees in previous post disaster phases are demonstrated on the Figure 1.1 and 1.2 (Şener & Altun, 2009).

Figure 1.1 : Examples of indoor modifications, indoor separations with curtains in order to provide privacy & space personalization (Şener & Altun, 2009).

Figure 1.2 : Examples of outdoor modifications, organizing a planting area in front of the house and creating outdoor spaces(Şener & Altun, 2009).

This thesis develops a model for designing flexible and adaptable prefabricated dwellings for post-disaster use. Temporary housing should meet the minimum requirement of adaptation and variety in order to create an acceptable level of comfort for the evacuees. The role of designers is to improve the level of living with better designs. As the German designer Dieter Rams describes "design should not dominate things. Not dominate people. It should help people." Design in this case is not a luxury affordable by wealthy people but a necessity that ease the life of people.

1.1. Fast, Cheap and Adaptable

This thesis proposes a parametric model that targets prefabrication systems. Since their production and assembly requires little time as well as being, low-cost and modular they can be adapted to generate fast, adaptable and affordable temporary houses for post disaster evacuees. The advantage of thinking of this model digitally is having a larger design space inclusive of various user-centered parameters. The model is able to compute varying designs responding to different cases for post disaster needs, minimizing the cost and time required that accommodates variety. The Figure 1.3 below demonstrates the cost and variety relation. In the Fordist production logic, mass production relies on the amount of repetition, the more you repeat the more you decrease the cost (left). Likewise, in this system the cost grows when the variation increases (middle). The far right chart illustrates the mass customization in which the variability is possible within an acceptable margin of cost increase (Smith, 2011). Within this approach, the proposed model adopts the low-cost prefab technology to variability through mass customization.

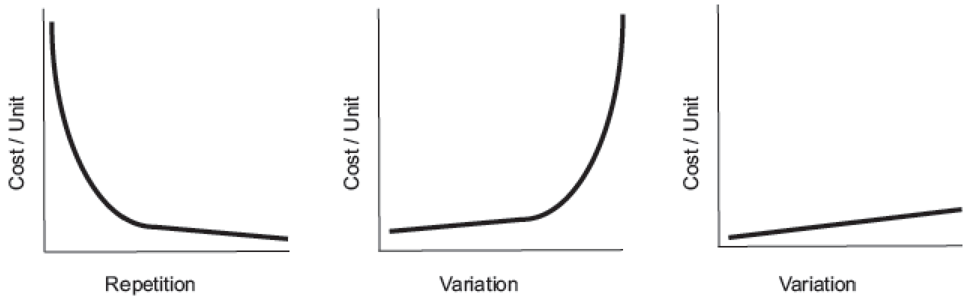

Figure 1.3 : Cost and variation charts (Smith, 2011).

The post-disaster recovery phase addresses many basic needs. It is important to not lose focus on priorities while figuring these needs: rapid sheltering is the one that comes first. In the digital model of the thesis, variables will be defined in accordance to the criteria briefly summarized in the previous section. These variables are essential inputs that affect the inhabitants' comfort and provide diversity. These will be described separately below. The defined inputs are linked to the general structure of the generative model. While the existing prefabricated temporary houses usually offer a single sized unit, in this model the importance of variations and adaptation is taken into consideration.

Size is the first input introduced to the digital model. In regular cases, one-size-fits-all solutions are applied in post-disaster interventions. However, the inadequacy of these solutions is observed in the past cases.

The second set of basic needs is related to climatic conditions. Climate is the input that affects the design at the scale of architectural details as well as material thickness, roof type and opening proportions.

Moreover, geography and land condition are determinants in the choice of the foundation type on which the living units are set on. Since the model has been developed to generate cheap, adaptable temporary shelters, it is essential to generate optimum solutions that suit any climate, orientation or landscape.

Last, but not the least, cultural aspects are strong factors in the design of healthy post disaster environments. The outdoor space configuration and the interior plan organization are dependent on cultural diversity and habits since privacy concerns and daily routines vary from family to another. Size, climate, geography and culture are determined as the primary variables to be taken into consideration in order to achieve more comfortable and more humanistic alternatives in post disaster house design.

The construction details in this model are mainly utilitarian. The steel structure is the most appropriate material for this model, not only for its recyclability and strength but also for the inherent qualities of the steel itself. The temporary houses developed in this model are durable and robust, allowing assembly and deconstruction for reassembly in future cases. The utilitarian details are designed within this strategy. The shell is made of a steel frame consisting of welded steel sections, the frame is integrally covered with SIPs. The shell is rugged and strong designed to stand stacking and live loading. Equipped for habitation, each temporary house within this project contains water and bottled gas, which can be refilled or connected to infrastructure resources if available.

1.2. Parametric Opportunities in Temporary Housing

While digital tools are increasing in the architectural design process, most of these tools are used to design unbuilt proposals with complex geometric forms. The pursuit of complex form building has shaded the powerful function of advanced modeling such as mass customization and highly buildable designs. Digital tools should be applied for simplification, standardization and modularization in order to achieve the perfect performance and mass-customization. Humanitarian designs are great opportunities that can benefit from the potential of the digital tools and wipe out all mass prefabricated and one size fits all solutions.

The constraints and user requirements discussed above can be achieved with the use of digital technologies such as a parametric model that generate temporary houses adaptable to different cases. The main goal of this thesis is to demonstrate that an open source parametric model is possible for temporary house construction. The significance of this study is that it suggests utilizing parametric tools in time of disaster, in order to make advantage of these technologies and develop variations and adaptable solutions within the resources and time shortage. It aims to achieve a successful design that would adapt to local climate and materials and can be built easily by the repetition of similar details, requiring basic tools and skills.

1.3. Constraints & User Requirements

In the time of disaster, recovery requires focus on the basic need of people such as medical treatment, food, shelter and basic services. However, on the long-term recovery planning, temporary settlements and housing construction are taken into consideration. Within the shortage of sources, material and time, mass prefabricated houses are applied to every similar post disaster recovery location without regarding any geographic or social differences.

Typically, in post disaster recovery cases, the evacuees are located in one-room container habitations that spread far from the city with minimal infrastructure, limiting choice of material and extending time of transportation (Yeung & Harkins, 2010). Families living in these habitations are expected to continue their work, studies and daily life. As observed in many cases these temporary houses turn into slum houses with the add-ons the inhabitant constructs. These modifications and add-ons are indications of the inadequacy of these one-size-fits-all solutions.

There are many examples around the world that confirm the failure of disaster recovery settlements in fulfilling the basic needs of their inhabitants. Şener & Altun (2009) illustrate in their study the kind and reasons of the modifications done in the temporary settlement after the 1999 Marmara Earthquake. They demonstrate that the indoor modifications are related to the user requirement of space partitions and privacy, while outdoor modifications are due to the user requirement of storage, additional spaces and individual recreational outdoor areas.

In summary, post disaster is a hard time with limited resources, a successful design would require economical use of simple locally obtained material that can be built easily and quickly with the most basic tools and skills, and allow participation of everyone on the community. The system should be designed to adapt various sites and user requirements and be easily replicated by communities with minimal external assistance (Yeung & Harkins, 2010).

The study is comprised of two different parts. The first part, gives the reader a brief historical context to general post disaster strategies and prefabrication from around the world converging to practices in Turkey. The second part of the thesis explains the proposal model.

Chapter two gives a review of the literature of post- disaster housing with focus on temporary housing. The problems identified in the introduction are discussed in this chapter with reference to various post-disaster projects. How parametric modeling and digital fabrication contribute to the post disaster reconstruction is discussed and exemplified.

Chapter three introduces the prefabrication (prefab from here onwards) manufacturing technologies. The criteria that contributed on the material selection are discussed. Manufacturing processes of steel structure and Sandwich panels are explained. Furthermore, the process of fabricating and the importance of adaptable details is emphasized.

Chapter four, the digital parametric model created for post-disaster temporary sheltering is presented in detail. The principal design decisions, how the parameters are quantified and embedded into the model is introduced. The use of software is elaborated and the parameters of the generated model are detailed.

Chapter five concludes by evaluating the developed model and makes suggestions for further studies. A brief evaluation of the parametric model is also provided. At last attention is drew on how to further studies can contribute to this research and move it to different scales.

2. BASIC CONCEPTS IN POST DISASTER SHELTERING / HOUSING

The basic emphasis behind the argument of this thesis is built on temporary housing. If we are to establish the definition of the temporary housing and defining the difference between housing and sheltering, we will realize that each recovery phase has different requirements in terms of scale and comfort. Further on, this chapter sets out a review of all post disaster stages in reconstruction and exemplifies the different designs done in the field focusing on different approaches. From these illustrated projects, we move to exploring the user and the state contributions within the two main reconstruction approaches in the post disaster, the technology-based and the community based reconstruction approaches. Moreover, the community based reconstruction approaches is discussed within the digital fabrication examples. The different user requirements on the other hand are questioned and discuss which will lead us to the main questions of this study.

2.1. Clarifying the Terms Sheltering & Temporary Housing

The meaning of the word shelter evokes diverse images in peoples’ minds. A study conducted by the Shelter Project in 2002 examines the proportion of aid spent on the shelter and housing sector explains that the key obstacle is the lack of clear definition of the sector along with agreements on terminology (Bauer, 2003). Although there are still contradictions in this field about the terminology, it is clarified what the two terms imply for within the context of this study. The figure 2.1 gives a brief idea about these concept within the permanence and time impact.

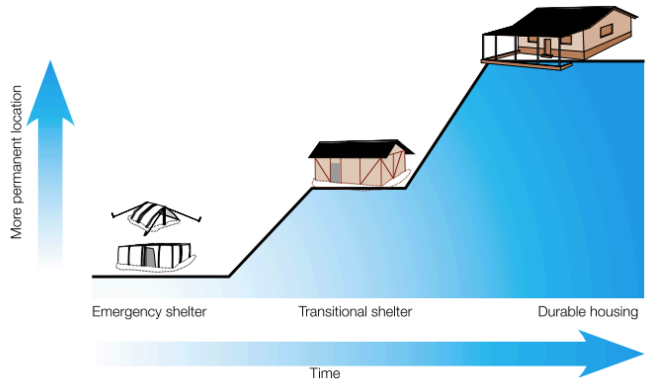

Figure 2.1 : The permanence and time impact on shelter and housing construction ("Transitional shelters," n.d.).

The main distinction between shelter and housing in the humanitarian context is based on the scale and construction time (Bauer, 2003). Furthermore, transitional shelters are defined to provide shelter between an emergency and the time when durable housing is completed to people displaced due to disaster ("Transitional shelters," n.d.). Although the definitions of the two terms sound similar there is an important difference between the two related to their implementation and usage time.

Mentioned by the United Nations as post disaster housing, referred by the red cross as transitional shelter, the conflict in the post disaster housing/ sheltering terminology is lasting. In order to define the design requirement is essential to clarify these two concepts. Qarantelli, positions to this conflict and defines the post disaster phenomena by separating the recovery process into four phases, emergency sheltering, temporary sheltering, temporary housing and permanent housing.

There are exceptions, in which temporary houses turn into permanent houses as in the case of Sicilian earthquake victims in 1968, because the permanent houses were never built (Quarantelli, 1995). The main motivation of this thesis is the temporary housing design because of the prolonged usage time of these houses and the challenge of fulfilling the requirements of these houses without being permanent. In the light of Quarantelli's categorizations, the model this thesis builds its study on, is the temporary housing phase of the post disaster reconstruction phases, in which the displaced victims, get back to daily day activities before they move to their permanent houses, which can take years in some cases.

2.2. Post Disaster Relief Design Phases

Qarantelli (1995) defines post disaster phases as, emergency sheltering, temporary sheltering, temporary housing and permanent housing. In this section, each recovery phase will be exemplified with contemporary realized projects and concept designs to understand each phase. Understanding how design and different material use are involved in critical times without increasing cost is examined. The question of why this thesis focuses on the temporary housing phenomena will be clarified.

2.3. Emergency Shelter

According to Quarantelli (1995), the term Emergency sheltering is to be used for short periods the disaster victims spend away from their permanent homes, as short as overnight. This can be their relative's non-damaged house or evacuation centers as governmental buildings in which the dislocated people are gathered to spend the night (Figure 2.2).

Figure 2.2 : The post tsunami shelter in before the partitions were put in place image courtesy of Shigeru Ban architects (Url-1).

The Japanese architect Shigeru Ban, has been working on diverse post disaster sheltering scales in order to answer the displaced people's need. After the Kobe earthquake in japan in 2011, many families found themselves living on the floor of shelters and gymnasiums, sharing one large space with strangers in the similar situation. Ban, concerned about the increasing stress that would influence the victims, he would look for a simple and comfortable solution. Although the people were located in safe evacuation centers, with the increasing crowd the privacy became a problem. As a solution Shigeru Ban develops a curtained partition system that would provide some comfort to the individuals since they had to wait months in the evacuation centers until the government provide them relief homes (Figure 2.3).

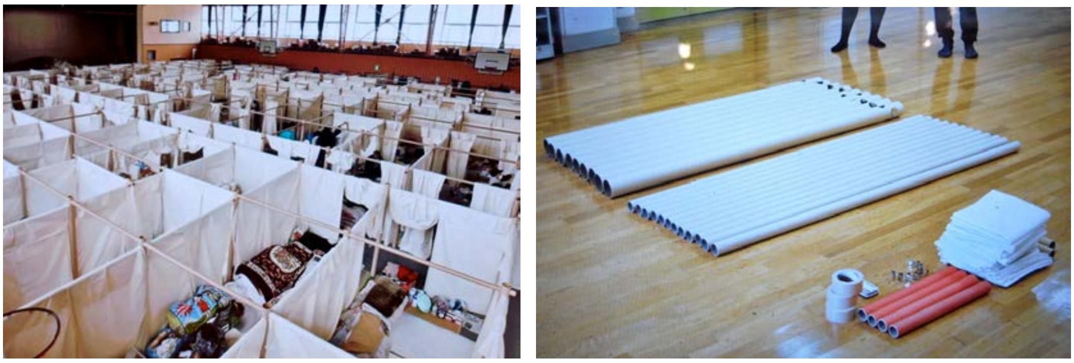

Figure 2.3 : Emergency shelter paper partitions' by Shigeru Ban Architects image courtesy of Shigeru Ban architects (Url-1).

The system was created of two sizes of cardboard tubing, plywood, robes and white curtains. This was a modular system that allows fast and easy assembly and disassembly at the same time since it was recyclable. The units could be built in different dimensions for different sized families. 1800 individual units of post disaster partition system were assembled in 50 short-term shelters for evacuees affected by the disaster.

Other materials for dividing large spaces shared with strangers were developed. One of these solutions is the one developed by the Canadian studio Molo, which is a system of paper partitions that would provide privacy at shelters in the wake of a disaster illustrated above in Figure 2.4. Called, Sofshelter, an accordion shaped Kraft paper wall, creates a personal space with the sense of community and privacy despite the uncomfortable conditions of emergency shelters (Figure 2.5).

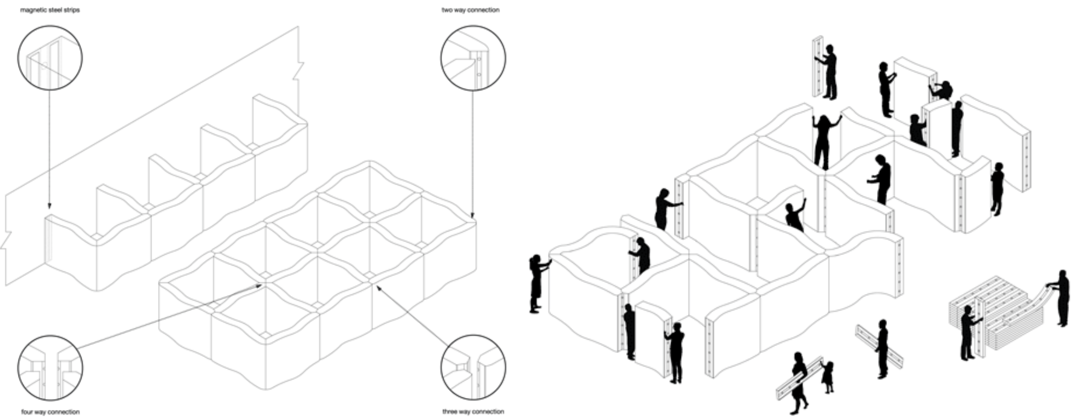

Figure 2.4 : Sofshelter, setting up a community of rooms (Url-2).

Figure 2.5 : Images demonstrating the space division and personal area definitions with Sofshelter (Url-2).

Both examples emphasize and focus on the personalized minimal comfort and privacy of the disaster evacuees and get adapted in size according to the family sizes, which is a sensible approach in rapid post disaster interventions.

2.4. Temporary Sheltering

Temporary sheltering refers to the people's temporary displacement into other quarters for an expected short stay. The major differences between the emergency and temporary sheltering are significant distinguishing for practical as well as theoretical purposes. Since there are no household routines established in the temporary sheltering the question of how the disaster victims will be fed for example arises as a problem to be solved (Baradan, 1995).

Tents are the first aid materials that reach the site after disaster. They are inexpensive and easy to set up, a single person or two can build a tent within a couple of hours. These provide private shelters with minimum space for the evacuees for short stays. In the 21st century, there is a range of design that offer a different tent systems and materials, most of them are either too experimental and expensive, or made of non-resistant material. 'Ha-Ori shelter', 'global village shelter' and 'recover shelter' are some of the most creative designs generated for temporary sheltering (Figure 2.6).

Figure 2.6 : The mock-up of the folding shelter Ha-Ori Shelter 2003 (Url-3).

Ha-Ori Shelter is an elegant temporary shelter designed and constructed by Joerg an industrial design student at the Royal College of Art in London. Stemming from Student's exploration of a folding technique inspired by the leaves of a hornbeam tree, the Ha-Ori (Japanese for "folding leaf") shelter is made of corrugated polypropylene folded in a series of trapezoidal shapes to create a rigid structure. When open, the shelter has a diameter of 3.81 m and a height of 2.5 m. When folded, the Ha-Ori measures 2.6 m x 0.45 m for easy transport.

Global village Shelter is a flat pack shelter achieved after more than a 100 different experimental forms to find the right method for this design. As demonstrated on Figure 2.7 the flat pack shelter is made with large sheets of fold-up corrugated laminated cardboard, flat-packed in three easily shippable parts. The already jointed walls have to be unfolded, and two roof pieces connected and placed on top. It is light and simple design to be constructed by two people in less than an hour.

Figure 2.7 : Images demonstrating the installation and usage of the flat pack shelter (Url-4).

Figure 2.8 : Recover Shelter 2008 (Url-5).

Finally, the Recover Shelter is another shelter design for rapid deployment in disaster relief (Figure 2.8). It is similarly to Ha-Ori Shelter made of a large single polypropylene sheet, which can be built by one person in a couple of minute. This temporary shelter can house up to a family of four for a month. This giant accordion shelter can be folded into a horse-shoe shape and staked together with occupying minimum space to be shipped to the disaster sites.

Conversely, in many cases the tents are shipped over long distances at a high cost to go at the end unused because they arrive too late or they were located at camps far away from homes, businesses and livestock. In such cases, local people shifted into self-reliance and they built vernacular shelters to cover their temporary shelter need.

2.5. Temporary Houses

It is important to define the distinction between sheltering and housing in order to understand the post-disaster recovery strategies since housing involves a wide range of expected functions. The housing concept involves continuation of the household responsibilities and daily activities in the new neighborhoods (Quarantelli, 1995). The displaced people may be placed in mobile homes, rented apartments or temporary houses, but the important fact is that differently from the temporary sheltering, the victims are expected to establish routines and start to get back to daily life activity such as school, work, etc.

The occupation of temporary housing may take years, even sometimes there are some cases in which the temporary housing turns into permanent housing if the permanent houses are not built such as the Sicilian earthquake survivors in 1968 (Quarantelli,1995). The ambiguous use of time makes the temporary shelters design very important in order to satisfy the minimal need of the evacuees during that long period.

The Japanese architect Shigeru Ban, has different disaster recovery works at different scales. After the great east japan earthquake and tsunami, he proposed three-story temporary housing made of shipping containers (Figure 2.9). By stacking these containers in a checkerboard pattern, he created a practical system, with open living spaces in between the containers. Three different types of plans were developed, 19,8m² for one or two residents, 29,7 m² for three or four residents and 39,6m² for more than four residents. The family sizes and fixed in furniture details were taken into consideration in this design (Figure 2.10). In many cases similar temporary houses ends up going to waste, nevertheless, Ban assure that these containers can be reused in future disasters.

Figure 2.9 : Multistory temporary housing designed by Shigeru Ban after the Japan earthquake and tsunami (Url-6).

Figure 2.10 : The interior of the container in the multistory temporary housing by Shigeru Ban (Url-6).

On the other hand, the CNC technologies and the developed CAM, CAD tools are dominating our lives and designs in every aspect. Small-scale houses can be designed and manufactured digitally. The instant house is one of the first examples developed to provide mass customized, designed housing to emergency and poverty-affected locations. Developed by Marcel Botha for a preceding research Professor Lawrance Sass (MIT), the instant house consists of all flat packed structure ready for assembly, with a process that gives utility to the end user, by the use of generative computational methods and Computer Numerically controlled fabrication techniques, to customize the design. The design process produces a customized, mono-material (plywood) structure assembled with the limited number of joint types (Figure 2.11). For building the first prototype it took two people three days to assemble (Botha, 2006a).

Figure 2.11 : The instant House Prototype for MoMa ‘the instant House’ exhibition (Botha, 2006b).

Based on a similar construction and material principle, the Wikihouse is an open source construction set. It is based on the idea of designing, downloading and printing you own house online. This is a CNC-milled house that can be assembled with minimal skills similar to IKEA furniture assembly skills (Figure 2.12). The designers are searching for using this model in post disaster recovery, in which speed and cost are two fundamental aspects. This may provide more personalized houses for the disaster evacuees with low cost and easy assembly.

Each example mentioned in this section is a source of inspiration in a different way. The Figure 2.13 below categorize their contributions in terms of personalized space, variety, digital fabrication and parametric design.

Figure 2.12 : The Wikihouse prototype (Url-7).

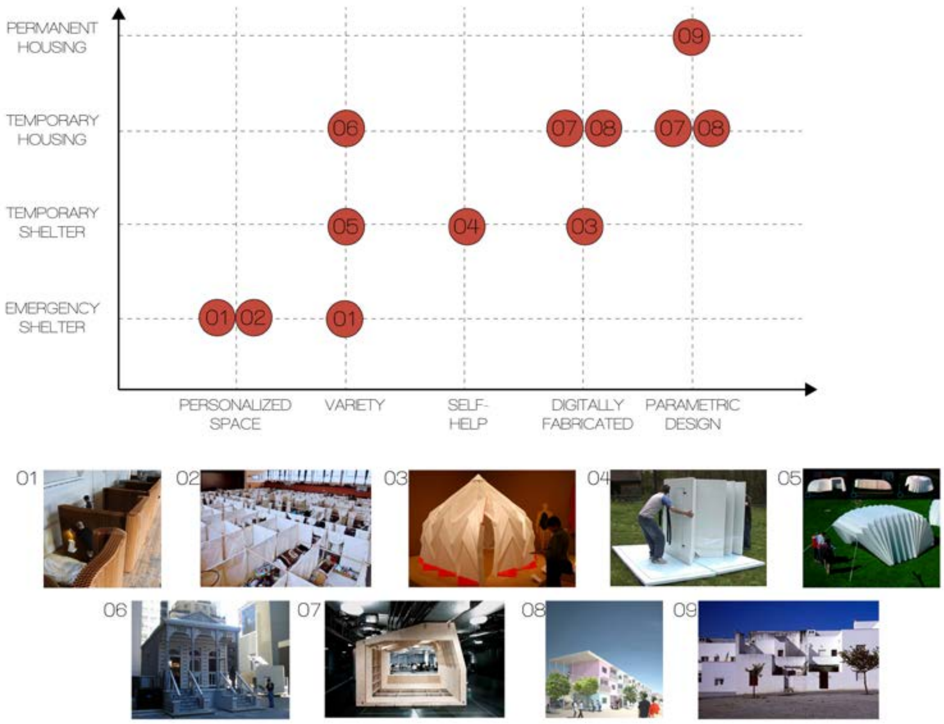

Figure 2.13 : Main types and contribution considered in each example.

2.6. Technology Based & Community Based Approach to Post-disaster Reconstruction

According to Baradan there are two kinds of basic approaches to the post-disaster reconstruction, one is the technology-based approach usually supported by a provider policy, and the other community based approach that can be defined as the post disaster reconstruction dependent on public participation.

Community based approach may be related to the 'self-help and mutual aid' concepts which constitutes an important part in humanitarian design. To understand its origin the history takes us back to the New Gourna Village example. Back in 1946, in Egypt, the architect Hassan Fathy planned New Gourna a new village settlement. The concept of this village was that the villagers were supported to build their own village with local material and construction methods. It took years to complete this village and at the end, the villagers were not satisfied with the result and this experiment ended up with an abandoned ghost village, a failure. However, Fathy's approach of building by the poor for the poor would have a profound influence on the growing team of the architects working on the issue of housing in the developing world. In 1949, a "self-help and mutual aid" project in Puerto Rico was given start. 67,000 farm workers were given small plots of land and the organized in groups of 30 to work on each other's home. Different from New Gourna, the families here were free to design and built their homes using any method. The project was successful and around 30,000 to 40,000 small houses were built by the 1960's. These "self-help and mutual housing aid" initiatives influenced John F. C. Turner, who began a similar program to rebuilt 10,000 homes destroyed by an earthquake in Peru, in 1958.

Although, designers offered up a range of innovative emergency-shelter systems, from inflatable warehouses to polyurethane domes, most of them were too expensive or too bulky to implement. Tents on the other hand, were the first choice of most aid agencies, they would be shipped in many cases over long distances at an important cost to go at the end unused because they arrived too late or they were located at camps far away from homes, businesses and livestock. Unlike innovative emergency shelter and tents, the sites-and –services and help-self models promoted self – reliance that makes the major difference.

2.7. How Parametric Modeling Contributes to Post-disaster Reconstruction

Many modeling programs and technologies transfer the embedded information from the design models toward the production process. Current technologies as Computer numerical controlled (CNC) machines and computer aided design (CAD) use the same language. This fact blurs the strict boundaries between design and fabrication that use to exist in the conventional construction process in which blue prints are the only communication tool. The CNC technology gets the design process closer to the production and the designer becomes more arbiters in the production process.

The post disaster reconstruction is mostly concerned with the construction and usually neglect the design due to the time and effort it requires, the digital modeling tools seem to be integrate the design for post disaster reconstruction because no time is required to adapt the design to the fabrication processes if they use all the same language.

Architectural mass customization, specifically in the development of transitional and low cost housing, is extremely beneficial. It allows the end users or housing recipients to have a home that responds to both their individual needs and the vernacular.

"Design for all" is the motto that motivates this work, therefore design should be integrated in the post disaster reconstruction in order to provide more personalized and comfortable temporary houses for evacuees and reuse the house components in future disasters. The evacuees either settled in tent or temporary shelter, they have needs and the aim here is to fulfill the minimum needs and user's requirements in order to create healthy and livable neighborhoods and communities.

2.8. Different User Requirement in Temporary Housing

In a study made by Sinan Mert Sener and Cem Altun after the massive Marmara earthquake in 1999, they made a detailed study that analyses the evacuees' adaptation at the temporary shelter settlement in Yeniköy. The study demonstrates that only 19% of the evacuees did not make any modification to their shelter units. According to the survey, 48% of the users have made modification indoors and outdoors, 30 % only outdoors and 3% only indoors. This study shows that the earthquake victims were not comfortable in the shelters and how they needed to make the modification for a better shelter. The main indoor modifications according to this study were, space partitions and privacy need and outdoor modifications, storage demands, need of porch at the entrance, additional storage need and individual recreational areas (Şener & Altun, 2009).

“There are minimum user requirements that need to be taken into consideration during the shelter design. In different scales of post disaster reconstruction the Japanese architect Shigeru Ban always includes variables such as scale and privacy as mentioned previously. However in most cases, identical shelters or containers are shipped over long distances no matter where, and the adaptation of these shelters may be difficult. The geographic and cultural conditions are different for each locations the containers are shipped to, thus the containers can not show adaptability to any location since they are identical.

In this thesis parameters such as family size, geographic and climatic conditions and privacy are the major inputs that form the design. These requirements should be taken into consideration and embedded into the design to provide personalized and comfortable shelters to the evacuees.

Mass customization is a must for the post disaster recovery, since variation and quality spaces are the right of everyone. Mass production is not the only option in recovery architecture any longer, with the digital modeling technologies mass customization is fast that can be adapted to any situation, precisely the post disaster construction.

2.9. How Community Based Approach Can Be Supported by Digital Fabrication

Disaster victims are highly affected by the damaged environment that surrounds them. A self-build approach is important, since it encourages the active participation of the disaster-affected community, it may be a useful way of restoring a sense of pride and well-being in people who have been through a trauma (Barakat, 2003). The time spent on reconstructing the environment and fixing the problems about sheltering needs is highly dependent on their motivation and recovery process. For instance to keep the victims involved in the reconstruction phase is an important motivation source that effects their trauma positively, as long as the evacuees are busy rebuilding, helping and gathering their strength, they recover much faster from their trauma. In this work community based approach is encouraged since no specific construction knowledge is required and has a great impact on victims post disaster stress recovery. The victims' inclusion into the construction process has positive social and psychological effects on them.

Digital design and fabrication methods differ significantly from traditional analog process. It provides a construction typology which discard paper based design methods requiring multiple layers of skill in order to generate, read and translate and construct, while also reducing mechanical dependency and increasing on site efficiency (Botha, 2006a). For instance in Instant House a room of 8' x 10' was assembled by two people over four days. Components can be small enough to be carried by one person, eliminating the need of cranes or scaffolding.

The aim is to present a novel design and prefabrication process for mass customized emergency. Disaster victims can be involved in the reconstruction process, if more simple details are produced. This maximizes the speed of construction and minimizes the labor cost, without neglecting its impacts on the victims' psychology.

3. TOWARDS AN EFFICIENT MODEL

As the design and manufacturing processes overlap more and more, manufacturing became a popular concept within the designers and architects in the digital era. Especially with the advanced technology in digital tools that fades the boundaries between design and construction, there is a major growth in the communication and fabrication capabilities. The increasing use of automation in construction through computer-automated design (CAD) and computer-automated manufacturing (CAM) software and computer numerically control (CNC) machines in factories lead to the direct use of design information in 2D and 3D for manufacturing and fabricating through automated machines (Smith, 2011). This brings the design and construction phases closer and increases the involvement of the designer and architects in the manufacturing process.

Traditional building design was based on 2D drawings (plan, section and façade). Building information modeling (BIM) extended the building design not only to the 3D but included time as 4D and cost as 5D. BIM covers more than just geometry but includes spatial relationships, lighting, geography, quantities, and properties of the building components. This is essential since all the information is transferred from the design phase to the construction phase without any information loss. In the post disaster recovery time and precision are must. To achieve variability with efficient time and cost control, BIM is a substantial tool. BIM and automation CNC manufacturing are the two current approaches that allow for better collaboration of interested parts and product customization.

In this project, the parametric model embeds information that provides variety in design. In order to transfer the virtual model information to the construction phase, documents containing the quantities and properties of the building components are extracted to be prefabricated and assembled on site. The assembly and disassembly of the structure and panels is important in post-disaster recovery cases. Therefore, the joints of the components are all mechanical to provide disassembly and reuse of the components in other similar cases.

The manufacturing process is a wide concept that includes the transformation of raw materials into finished products (Smith, 2011). Manufacturing includes all the transitional processes required for the production and fastening of the finish product's components. Various manufacturing processes can be listed as casting, molding, forming, machining, joining and rapid manufacturing, etc. however we will focus on three of them machining and fabrication.

There are two essential construction products for the realization of the post-disaster temporary houses. The frame of the houses is shaped with steel components and the shell is covered by sandwich panels. In Turkey, the prefabricated building industry is dominated by steel structure either mild steel or aluminum and sandwich panels.

3.1. Steel Structure

Steel has been used as a primary structural material since the industrial age. It is the most common in use material on contemporary steel frame construction, illustrated in the Figure 3.1 below. Structural steel is assembled with bolts or welds for attachment. In this project, welds are not preferred since it does not allow disassembly of the components that is why bolted connections are opted. Simple and uniform connection details in prefabricated structure gain importance for speed and ease of assembly. The mild steel structure can traverse large spans but in this case, there are 125 cm spans between the profile sections, this span is arranged according to the panel dimensions. In such a structural system, the panels can be attached to the structure on only one side or both sides; in the case of using panels on only one side, the structural profiles may create thermal bridges.

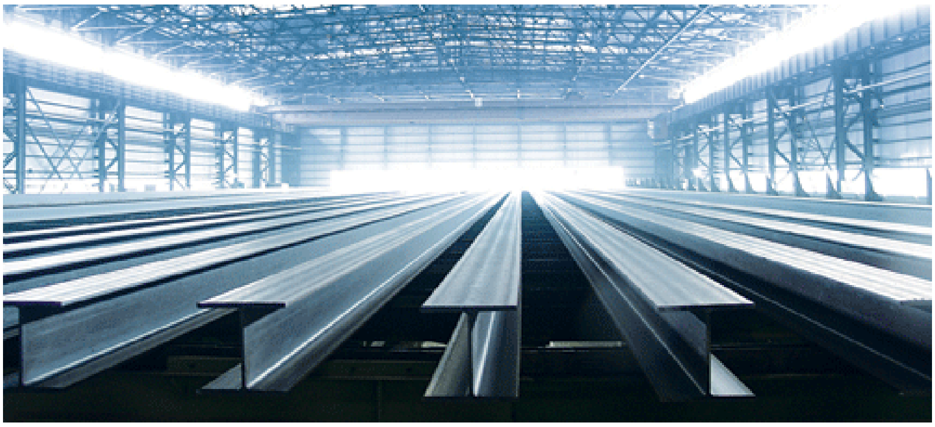

Figure 3.1 : Mild steel profiles (Url-8).

Aluminum profile (Figure 3.2), is not usually used as a structural element, however in prefabrication it is used in short spans with dense connection. It is very precise in comparison with mild steel since it is manufactured by extrusion and cutting. It also has many different shapes and sectional profiles, it is light and durable however it is more expensive and requires more details and amount of material (Smith, 2011).

The prefabricated model used in this project has been designed according to mild steel structure due to its attachment style, price and ease of details.

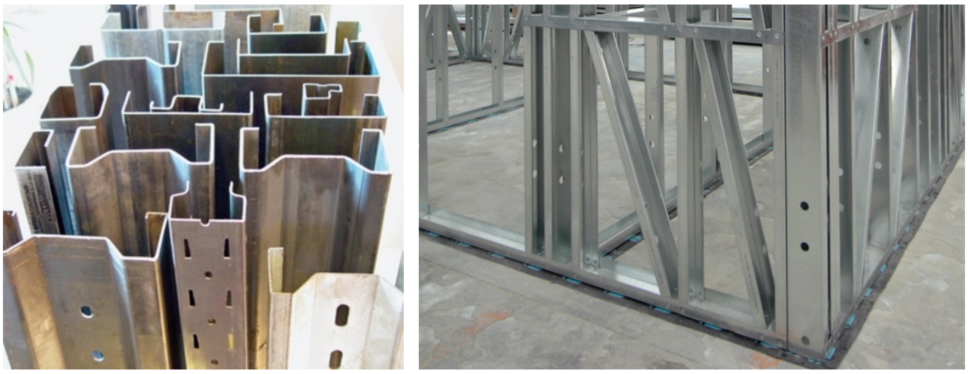

Figure 3.2 : Aluminum profile and joint details (Url-9).

3.2. Sandwich Panels

Sandwich panels can be manufactured on automatic continuous production lines, cut at required lengths automatically, packaged, and made ready for delivery and use, as seen in Figure 3.3. Since the panels are light, this provides great benefits during transport and assembly. In this way, the panels can be located on the requested form in quick, easy and secure way. It is possible to erect whole of the wall in very short times. The openings for the windows are cut away prior and the required formations for the electrical installation is prepared during the production (Smith, 2011). These preliminary works and the ease of assembly provide savings of time and labor during the construction and hence lower the cost of the building.

Figure 3.3 : Sandwich panel manufacturing machine (Url-10).

3.3. Fabrication

Fabrication is the process of taking the previous operations of manufacturing to assemble elements for buildings. The main aspect that differentiates fabrication from other processes of manufacturing is the concept of bringing two or more manufactured pieces together. Fabrication is the final process before the product is released for use.

The aim of this study is to present a novel design and prefabrication process for mass customized emergency solutions. All the material selections and the detail solutions are chosen accordingly. Labor is an important input in the fabrication process in terms of construction cost and time that is why the disaster evacuees are thought to be involved in the reconstruction process. This will maximize the speed of construction and minimize the labor cost, at the same time it will have improving impacts on the evacuees' psychology.

The prefab industry is a very challenging and competitive field. During the market research, none of the local prefab manufacturer's shared their fabrication and assembly details. It is know that each manufacturer developed its own details and apply them secretly. This is a very subtle industry with high competitive opponent manufacturer. Since the local prefab market was rules by these unspoken regulations, the parametric model developed in this study has an open edge in relation to joinery details and fabrication. Different manufacturers can apply their traditional detail solutions to this parametric model. The aim of this study is to gather the existing information and apply is in case of emergency as fast and affordable as possible.

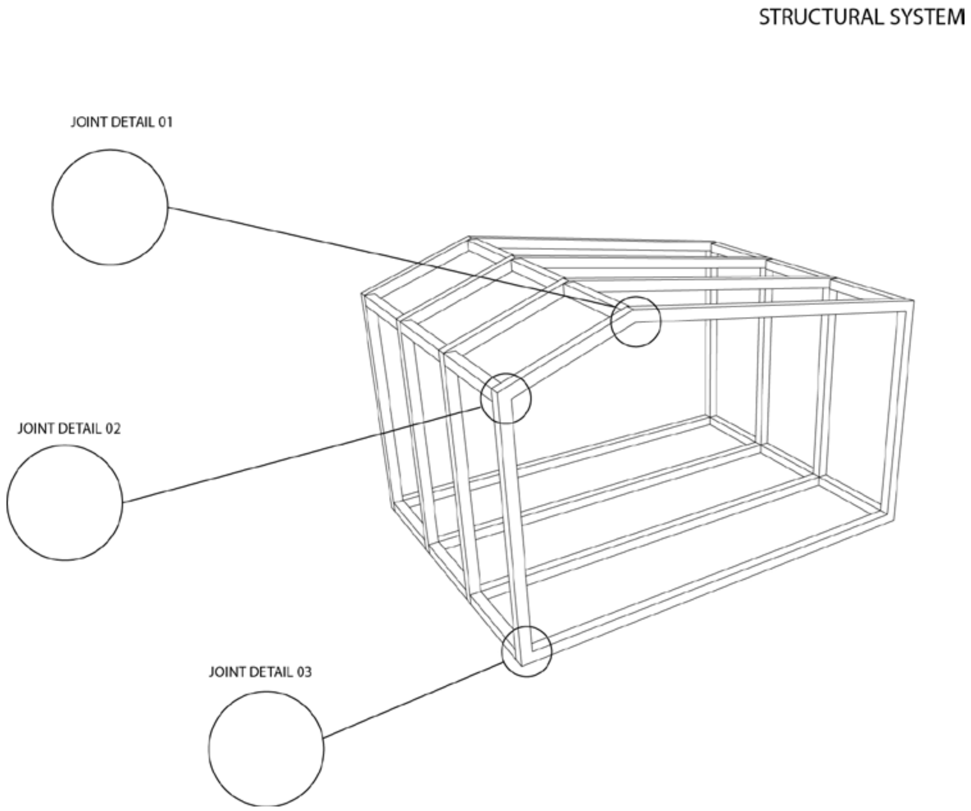

Figure 3.4 : The three main point details of the structural system.

Three main details pointed in Figure 3.4 are embedded into the parametric model, which can be modify by the manufacturer information. The parametric virtual model developed in this study enables interventions of the contractor as well as the design team. This is a dynamic model that adapts and varies according to local market, material analysis and geographic information. A parametric prefab model that varies and adapts to the changing environment is projected instead of the one that fits all prefab solutions for post-disaster recovery.

4. THE DIGITAL MODEL OF TEMPORARY PREFABRICATED HOUSE

4.1. The System, Design & Design Parameters

This thesis proposes a digital model that generates customized, habitable prefabricated living units for post disaster temporary housing, fabricated rapidly in a limited period with limited resources. The urgency of the temporary house design created in this thesis, approach the problem by dividing it into manageable pieces in which digital tools are used to solve the problems each regarding the nature of the problem. Different tools are used in each stage these tools may vary and expand over time in order to achieve more effective solutions thought the design and construction process as demonstrated in the Figure 4.1 below. The process starts with determining and evaluating the requirements before it converts each of the requirements into quantitative parameters. The design is molded by these parameters within the parametric model that process the design and generate the final product. In order to fabricate and construct the end design, the model generates documents and drawings of the final design for procurement and construction. Finally, the end product shelter is fabricated and constructed according to the documents extracted from the 3D parametric model. Once the material procurement is fulfilled and delivered to site the construction is lunched.

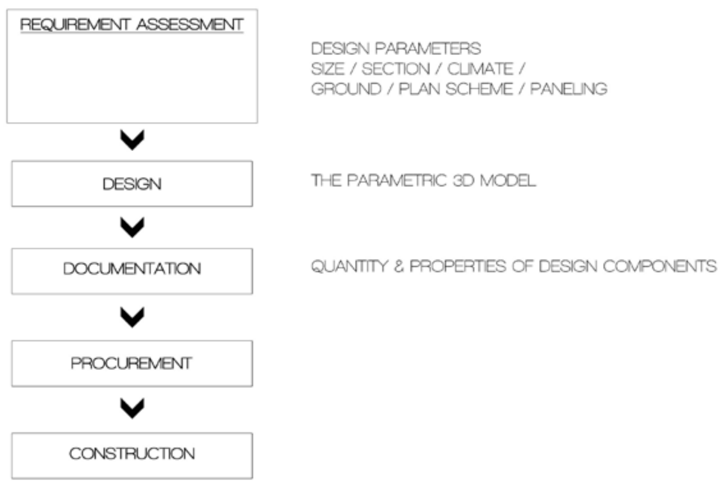

Figure 4.1 : The process and its subset components.

4.1.1. Assessment of requirements into parametric modeling

There are user requirements and choices that are taken into consideration during the temporary housing design. In this project, the parameters of the temporary housing design are defined under five headings: size, section, climate, ground, plan scheme and paneling. In this case family size, geographic, climatic conditions and privacy are the major input that shapes the design (Figure 4.2). These requirements are transformed into input and embedded into the parametric model.

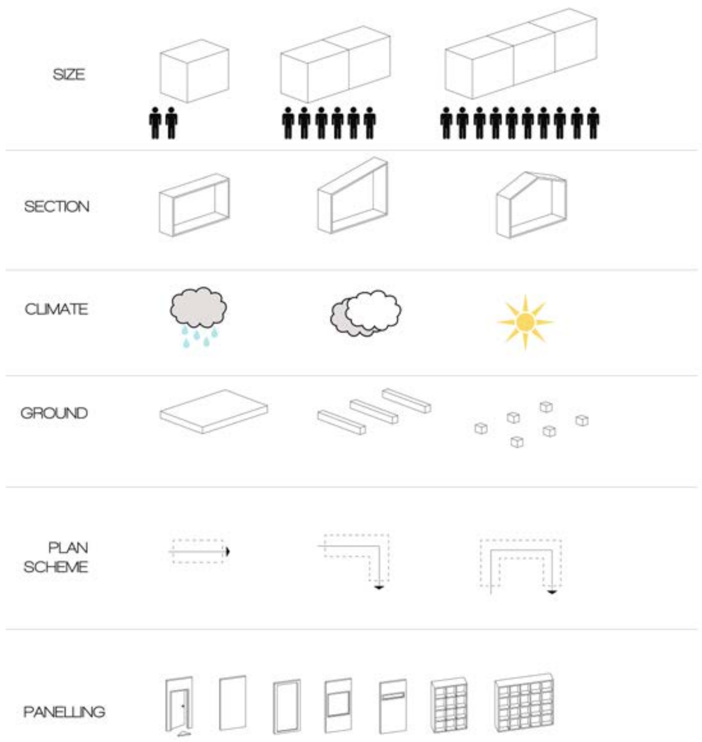

Figure 4.2 : Parameters of the prefabricated temporary houses.

These parameters demonstrated with abstract graphics in the Figure 4.2 above, are converted into quantitative inputs in the parametric model. First for size, three different options are specified. Size one is a shelter with a private room and a living room for 1 to 2 people with footage of 36-42 m². The size two contains two private rooms and a living room can host 3 to 6 people within a 70-80 m² area. The size three with three private rooms and a living room accommodate 7 to 10 people requiring an area of 90-95 m² (Figure 4.3).

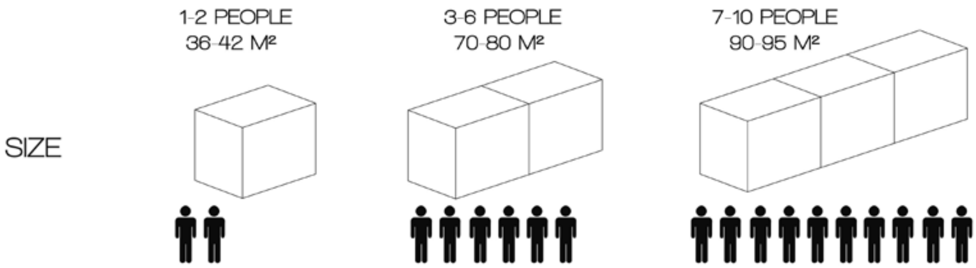

Figure 4.3 : The three size options available in the model.

The number of its future inhabitants determines the size of the shelter. This is the first parameter introduces to the model. After deciding the size of the shelter, the process of the model moves to the next step: the shelter's section.

Section is the frame that determines the structure of the shelter. The roof slope and shelter height are determined in this step. For section, there are four control points in the digital model (Figure 4.4). These four points define the silhouette of the shelter, which will be arrayed in a defined distance to create the structure frame.

The first point is the origin point, it is the base point which define the start point. The width (L) of the unit is defined by the distance between the second point and the origin point on the x-axis. The width of the units is restricted by four panels (L= 4 x panel width). The length of the shelters however is extended in relation to the size and plan scheme preferences. The height of each unit is defined by the distance between the third and base point on the y-axis. The panel dimensions restrict the height of the units, in this case, it fixed and equals to 300 cm. The third point is the midpoint on the upper edge of the section that defines the roof type. Two different sliders determine the coordinates of the peak point in each axis. The upper and lower limits on the x-axis are the two opposite sides of the model that define the model's width. The slider for y-axis is set within the interval of zero and L/2 (Figure 4.5).

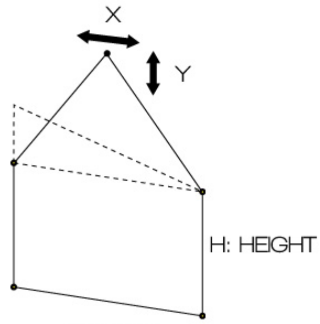

Figure 4.4 : The control points of the section.

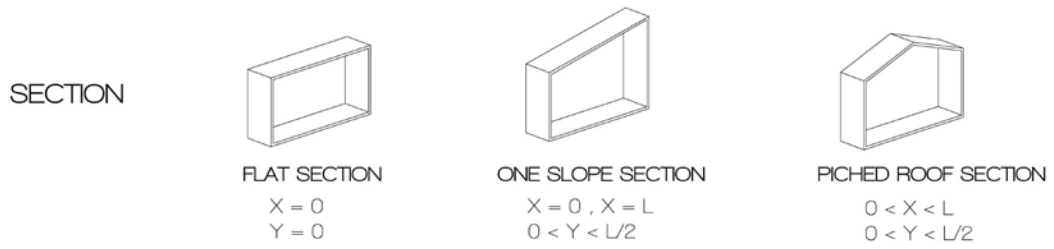

Figure 4.5 : Flat, One slope & pitched roof section options.

Since the model is done with the size and section parameters, it is time to introduce the next parameter that is climate. This parameter affects different inputs such as the model's section, the type of foundation and the material selection. There are three type of climate input that affects the shelter design. Cold, cloudy and hot weather are the three main weather conditions taken into consideration within this model.

The climate input affects the width of the material, which is established according to the accurate information of the local material, assigned. In this case sandwich panel are selected as default paneling material since it is a cheap material and easy to attain. In the model, the panels are used in three different widths which are set up according to the current market, as 8, 12 and 20 cm. 8 cm panel is commonly used in interior partitions while 12 or 20 cm are opted for exterior panels dependent on the weather severeness and climate (Figure 4.6). In case of hot or cold climate, it is ideal to use thick material such as 20 cm, in order to achieve insulation. On the other hand, for cloudy weather a mid-thickness panel of 12cm is opted.

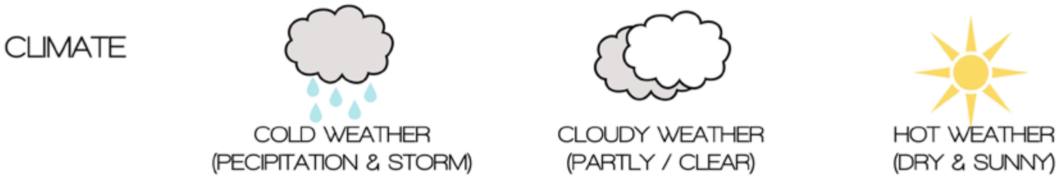

Figure 4.6 : The three different climatic conditions

Next, the ground characteristics and topography are introduced as parameters that determine, the type of foundation is established. There are three type of foundation in this model, each of them accommodate diverse circumstances (Figure 4.7). The three type of foundation that can be used for modular construction are piers, linear stem wall and full stem wall. Pier is a better solution in stabilizing different ground levels, while linear and full stem walls are better solutions in distributing the load.

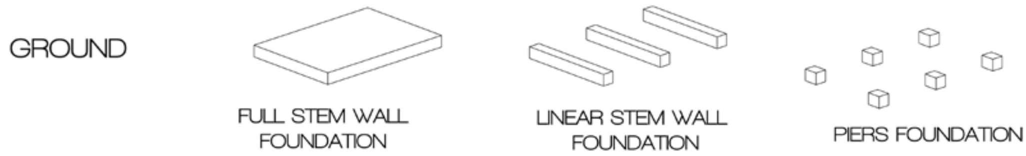

Figure 4.7 : The three types of foundation.

Once all the parameters mentioned above are set, the plan scheme is formed. On the plan base, there are three different options in the model for the moment. These options may increase and vary by introducing new schemes. The plan scheme is completely related to the user references. It defines privacy and the open spaces of the living unit. This part of the process will be discussed on the next section.

To sum up, the size and plan scheme are two parameters adjusted according to the user's information and requirements, large families need large spaces. However, section of the units is related to the climatic conditions and the material choice. Moreover, climate is linked to the roof design decisions, foundation type and the wall and material thicknesses at the same time and plan scheme defines privacy and the open spaces of the living unit.

4.1.2. Design and design parameters

This project opts to generate customized, habitable prefabricated living units for post-disaster temporary housing, manufactured rapidly and constructed in a short period of time with a low cost. The model requires the development of an automated generative system, first for the shape design (plan layout) and secondly for the fabrication (construction). The process is divided into two stages namely, shape design and design development. Within these, the design evolves from the plan layout to the 3D model. The two processes coexist, setting a framework for customization.

4.1.2.1. Shape design

The shape design deals with the customizable parameters defined according to the user profile and preferences such as plan scheme and paneling. This part of the model deals with articulations such as outdoor space, entrance direction and indoor privacy preferences.

The process start with a basic adds on grammar to define the plan scheme. Three basic living unit groups are defined: private room, living area and sanitary spaces. The most private set up includes different size bedrooms or praying areas. There are three different size of the private room. This type of room can be furnished with double bed, bunk bed, double bunk bed or can be left empty to accommodate different kind of functions such as meditating, praying or working.

The living area is a space designed to answers the daily life needs and contains spaces such as the kitchen, dining and sitting areas. There are three different size of the living area, each of these is matched according to the shelter size, because the inhabitant number is critical in space requirement for sitting and dining.

The sanitary units are independent units with sanitary connection that includes a shower, a toilet and a sink. Two sizes are predefined for this unit, one with linear and the other with square spatial arrangement.

The width of the modules is fixed by three panels and is the same for all living, private and sanitary. However, the length of the modules varies according to the shelter size. Different module sizes are demonstrated on Figure 4.8 below.

These adds on units mentioned above are linked by the circulation space. The circulation of the shelter is defined in three options I, L or U.

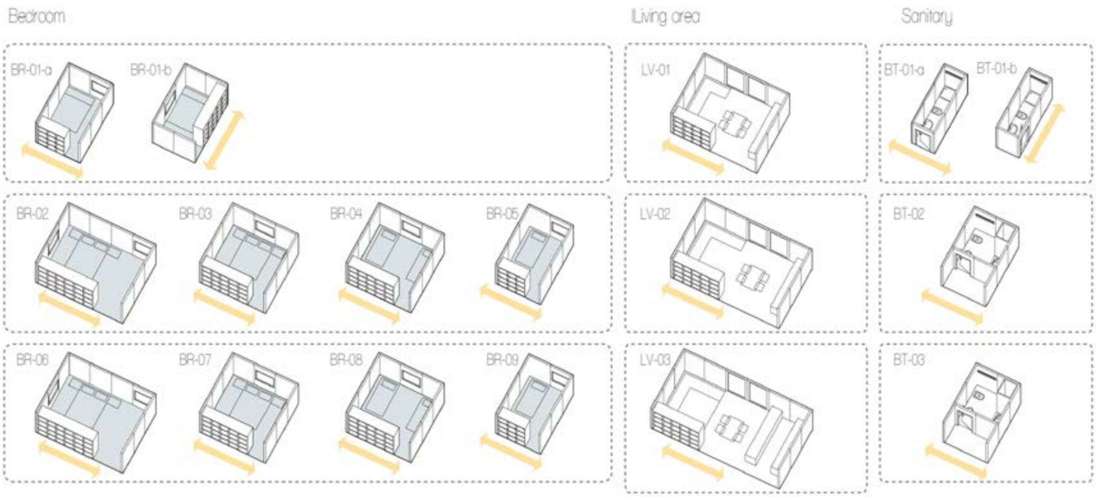

Figure 4.8 : Type of Modules under three main groups, sleeping, living and sanitary modules.

Plan scheme is the outline that defines how the units are add on to make a shelter. Since the circulation paths the outline of the shelters, there are three different circulation options embedded into this project, I, L, and U (Figure 4.9). These plan layouts may increase such as T, Z, etc… The plan scheme is interrelated with outdoor spaces because the unit arrangement in a manner affects the outdoors and defines them as open, semi-open or private. In Figure 4.10 three different plan layout options are generated from the model.

Figure 4.9 : The three different plan schemes proposed in the model.

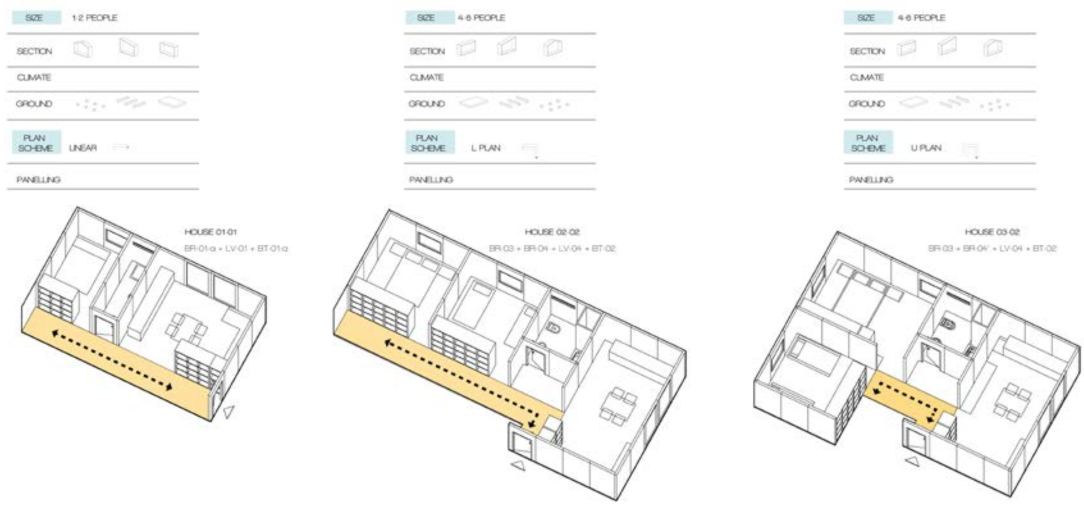

Figure 4.10 : The different house examples generated from the parametric model.

Once the plan layout is set up, the panels are generated according to the validated living units. The window and door opening in each panel and their dimension are arranged according to their living units, the sizes of each of these opening are adjusted according to the shelters' orientation and the climatic conditions. Window opening are set in the width of 100cm and the height of 50 to 200 cm. Since the prefabrication of customized fenestration is expensive and requires time, the window opening are fixed as three type of opening, first private window 50 x 100 cm, second regular window 120 x 100 cm and finally large window 200 x 100 cm . These dimensions can be modified, multiplied or adapted according to local market stocks and available production ratios. The types of panels used in the model are predefined and introduced to the model, all panel types are demonstrated in Figure 4.11. In Figure 4.12 different opening options are demonstrated both inside and outside the shelter. Outside the shelter the opening are available in three options which vary according to the shelter orientation and climatic conditions. Inside partitions can be either private solid panels or semi-private storage partitions.

Figure 4.11 : Types of panels used in the model.

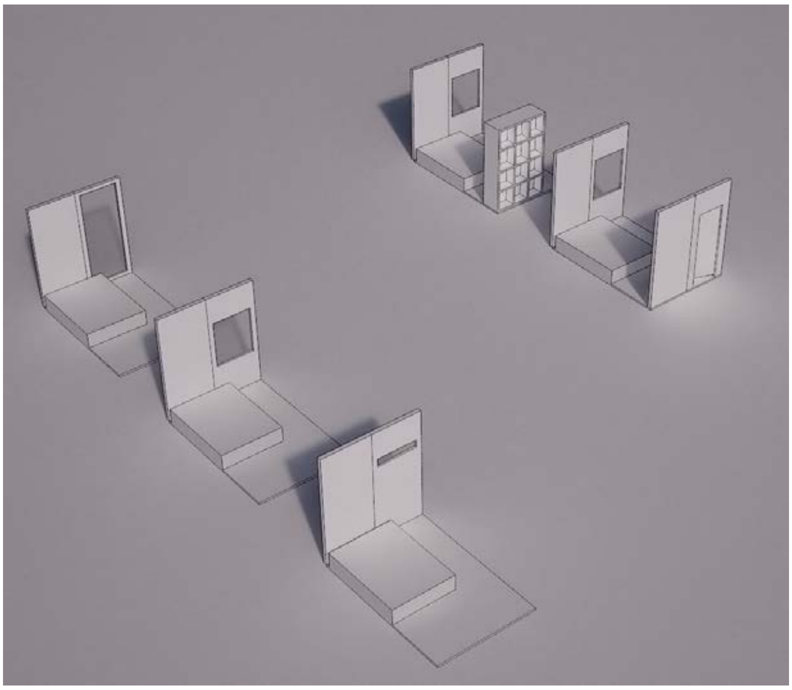

Figure 4.12 : The paneling options related to privacy and climate parameters.

The chosen plan layout and opening preferences concern the outdoor spaces. Previous studies demonstrate the importance of outdoor space in terms of sociological impacts, embracement, personalization and aesthetics. Balcony, courtyard and entrance preferences are resolved within this process of design.

Indoor partition panels are based on the user’s preferences and related to the privacy and storage space requirement. In the highest privacy level, all the indoor partitions are solid panels on the other hand, with the highest storage requirement most of the indoor panels would be visually permeable storage units (Figure 4.13).

Figure 4.13 : How privacy parameter affects interior panels.

Plan scheme, privacy settings (panels) and outdoor preferences are embedded parameters in the first phase of design that compose the plan layout of the units and generate the plan layout. This 2D AutoCAD format plan layout would be exported into Rhino in the second phase of the design process, to develop the 3D model. Material selection (climate), the unit section (structural profiles) and the foundation (ground) are the parameters evolved in the second phase of the design process.

4.1.2.2. Design development

The building outline and plan boundary have been decided in the previous phase of the design process. The task of this phase is to build the structure in the third dimension and cover the structural profiles with panels assigned according to the rooms they surround. The same room layout may reflect different opening according to the climatic and privacy reasons. Once the building geometry, wall opening and roof forms have been decided, the model develops all construction information needed for manufacturing and assembly.

This 3D model establishes a bridge between the design and fabrication. The system starts with a plan boundary as a surface model, and then rules of construction define the structural geometry and material choice of the shell.

The chosen shape model is covered with 8, 12 or 20 cm SIP in accordance with the climatic conditions as mentioned in the previous section. The design is settled on the foundation that the terrain requires. The window volumes are subtracted. The orientation of the openings is located to provide quality daylight and prevent heat loss. The interior panels are arranged as storage units or solid panels in accordance with privacy preferences.

There are many parameters and constraints in the grasshopper script. The major inputs are the size, the sloop of the roof, type of foundation, plan scheme (panels) and structural profiles. All parameters are interrelated to different degrees, but can be classified into five categories:

1. Profile
2. Panels
3. Roof
4. Foundation
5. Joints

The structural section profiles are defined by external points exported from the 3d model. The five points define the section curve that determines the height and the width of the shelter unit. All the points are predefined and cannot be moved unless the mid top point which is connected to two different sliders, one controls the move horizontally and the other vertically (Figure 4.14). That is how the roof can be arranged and designed at different scopes. The sections may have different thickness and width according to the climatic conditions and according to the material variation. Sliders that are defined within the 3D model offer determined spectrums for each input that provides variety. Figure 4.15 demonstrates the structural section profile generated by the model.

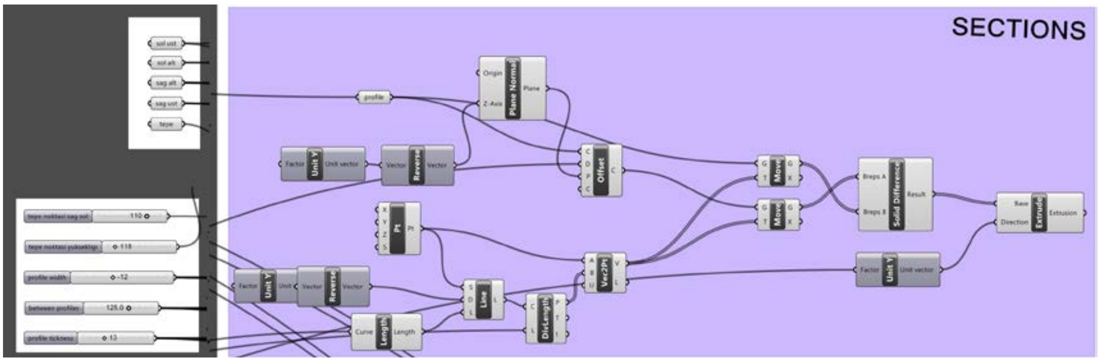

Figure 4.14 : The model definition of structural section profiles.

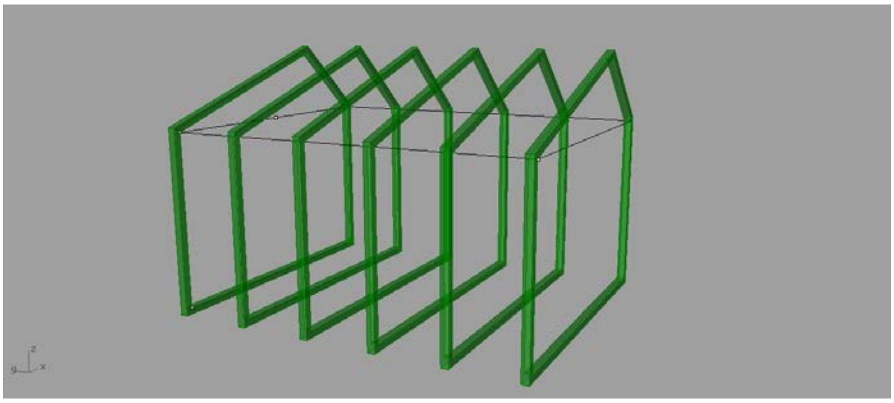

Figure 4.15 : Structural section profiles

Paneling is the array operation of the panels filling the distance between the vertical section profiles (Figure 4.16). Different panels are scattered according to the predefined special requirement mentioned in Chapter 4. The height and the width of the panels are constrained by the length of the section profiles, however the panels' thickness is changeable according to different environmental conditions that is connected to an independent slider in the model (Figure 4.17).

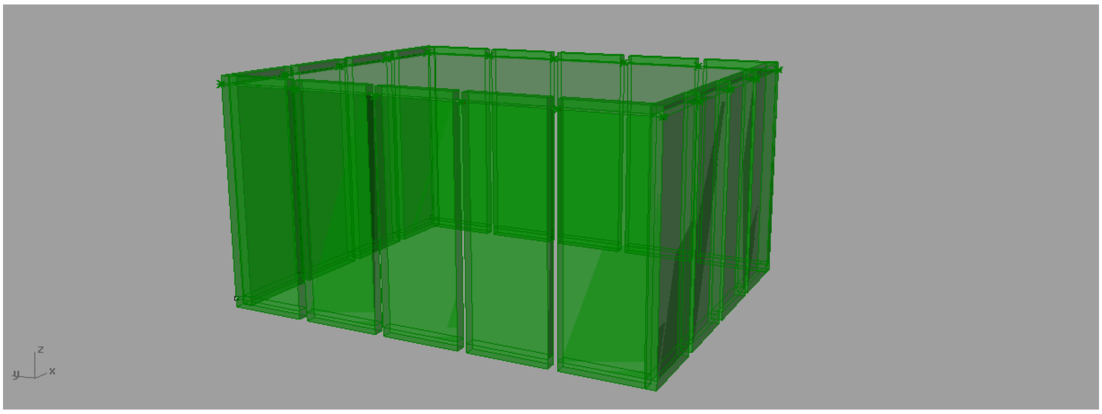

Figure 4.16 : Panels

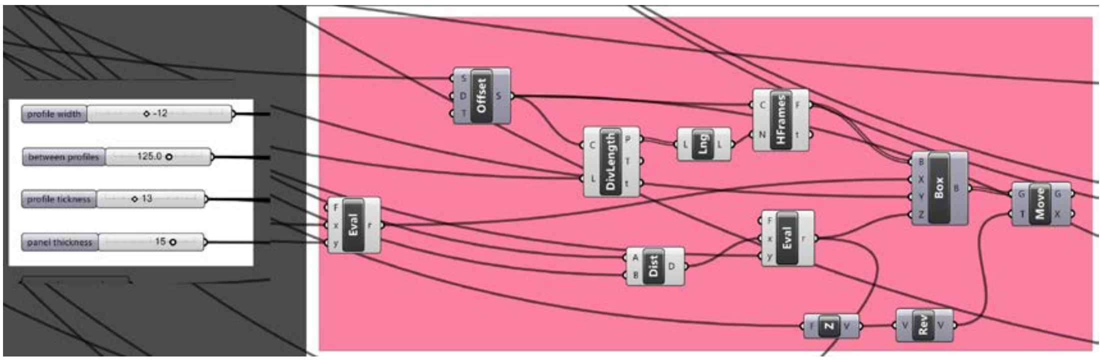

Figure 4.17 : The model definition of panels.

The roof panels similarly are created according to the slope completed from the sectional points. The panel thickness is connected to a different slider output. In order to create a canopy the roof panel edges are extended as much as their thickness (Figure 4.18 & 4.19).

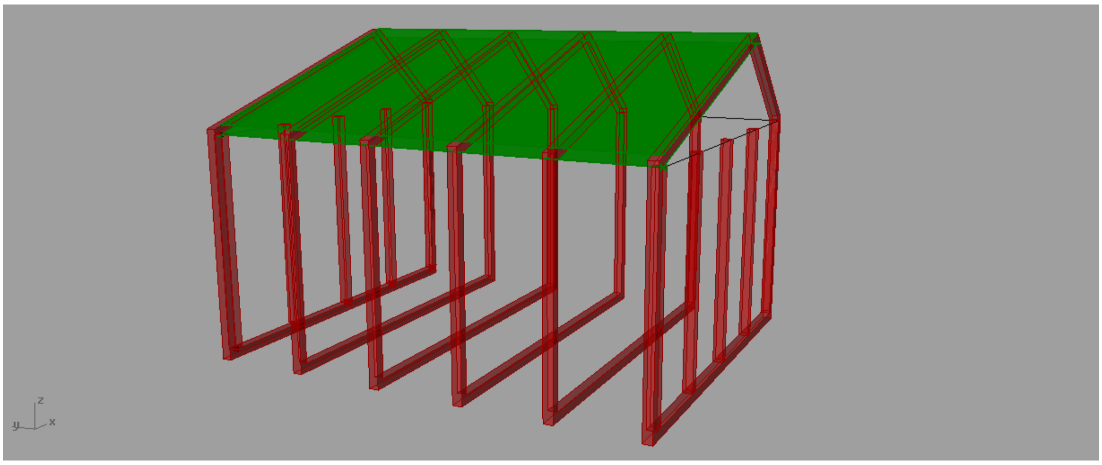

Figure 4.18 : Roof

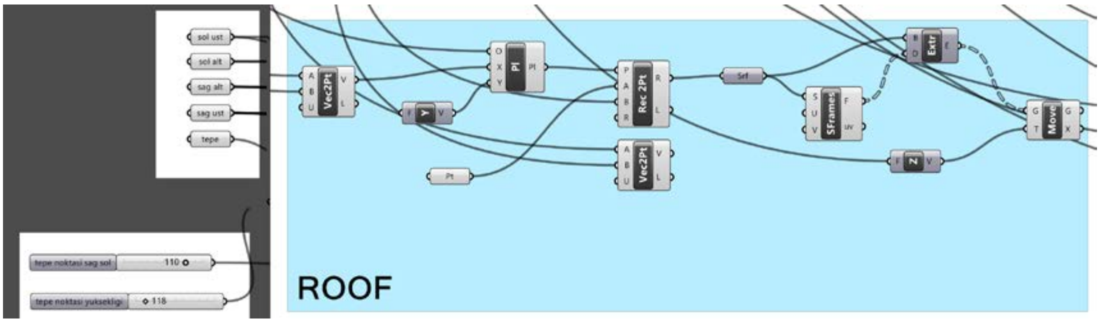

Figure 4.19 : The model definition of roof.

There are three types of foundations, one is the pier, the second is linear stem wall and the last one is full stem (Figure 4.20). Modular construction can be designed to distribute load to vertical structure at corners alleviating the need for full-engaged stem wall bearing at the perimeter of the module. The foundations are connected to the plan layout curve (the given geometry) that is an external reference from the rhino model imported into grasshopper, demonstrated on Figure 4.21. Another input defining the foundations is the foundation thickness defined by a slider, which allows flexibility in the foundation thickness that shapes according to different ground types.

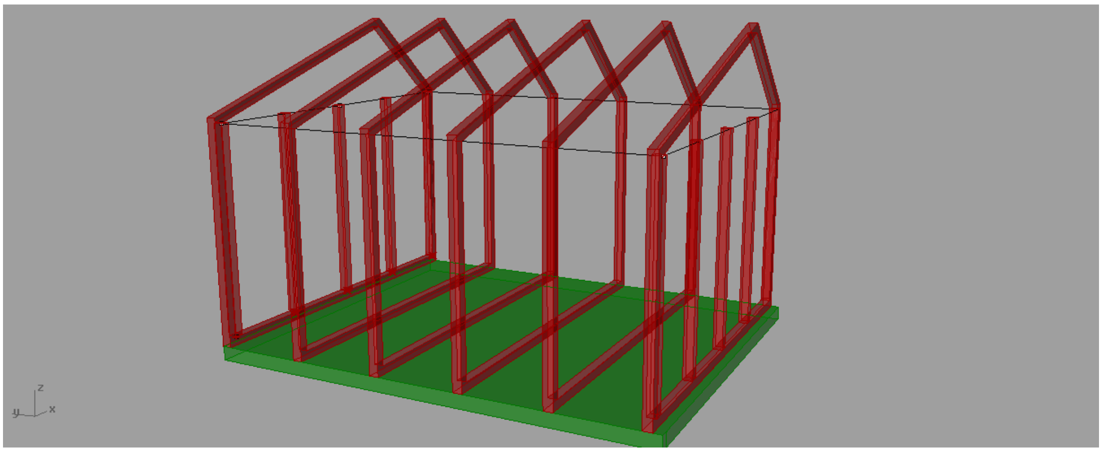

Figure 4.20 : Full stem foundation

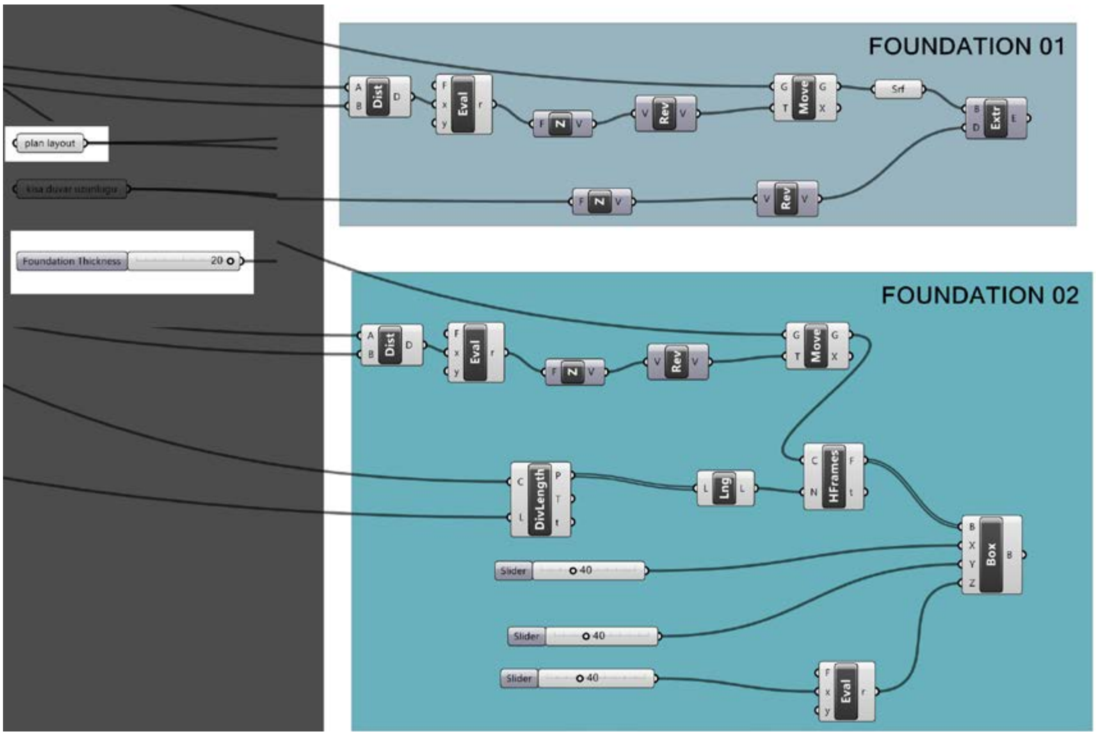

Figure 4.21 : The model definition of roof.

Joints are the horizontal connections that bind the vertical sections (Figure 4.22). Since the width and thickness of these profiles have the same value as the sectional profiles, they are connected to the same sliders so that they can be modified simultaneously (Figure 4.23). The length of these profiles is related and connected to the distance define in the offset of the vertical sectional profiles.

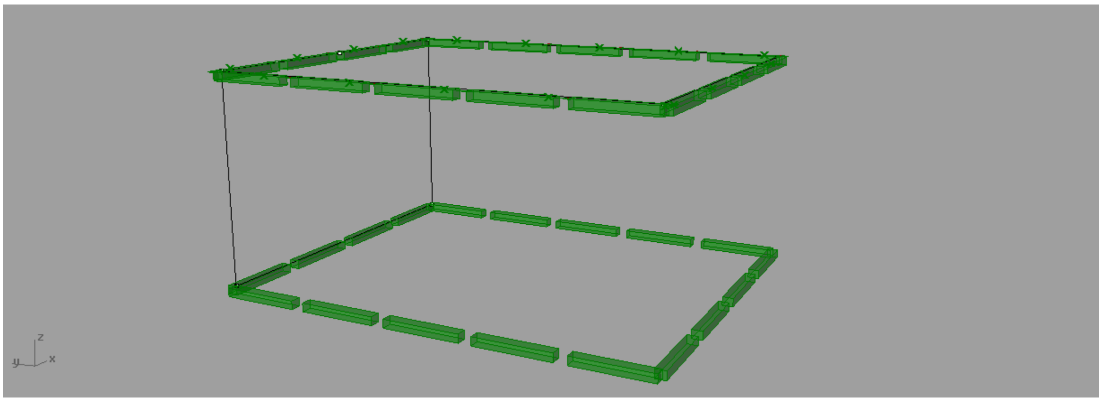

Figure 4.22 : Horizontal connections

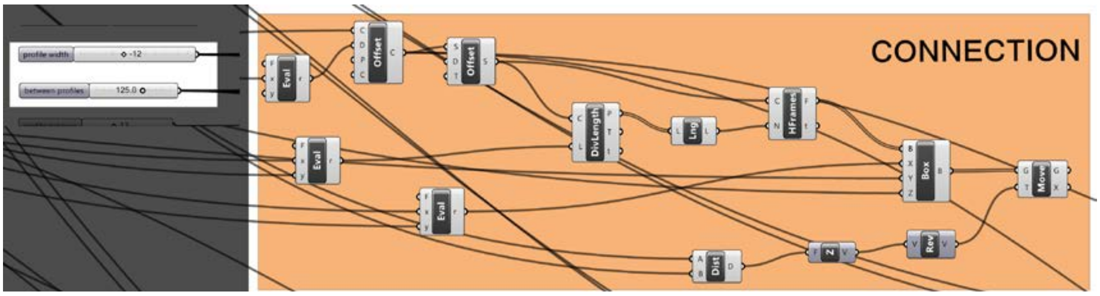

Figure 4.23 : The model definition of connections.

The model generates infinite solutions within the given parameters. Some of these options are shown below in Figure 4.24. These can be increased and varied according to different situations. The aim of the model is to generate similar solutions in term of details, construction methods and material yet diverse shelters answering different requirements.

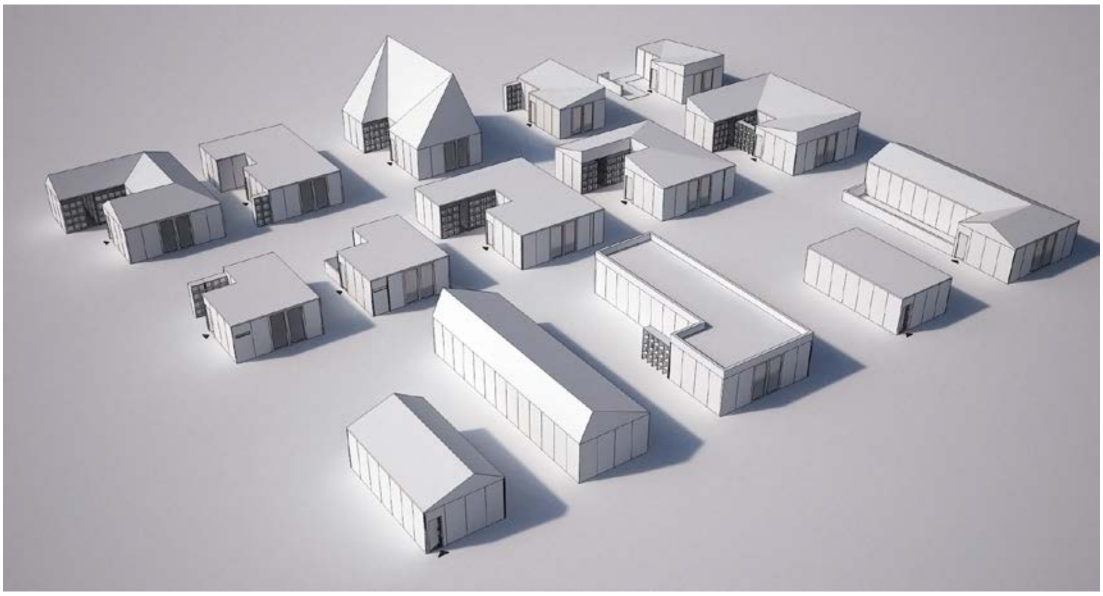

Figure 4.24 : A variety of models generated through the process.

4.1.3. Output: documents for procurement and construction

Once the desired final design is achieved, the following documents for procurement and construction from the model can be extracted:

Final list of quantity

List of steel members

List of panels

File for laser cutting

A physical model was constructed during the exploration process in order to experiment the computer controlled and conventional fabrication methods of the digital model. The prototype raises the opportunities to evaluate the design and construction process and integrate feedback to improve the sub sets of design. Although it is flexible, yet it assists in the problem of formulation and in organization of decision making during fabrication and construction (Figure 4.25- 4.29).

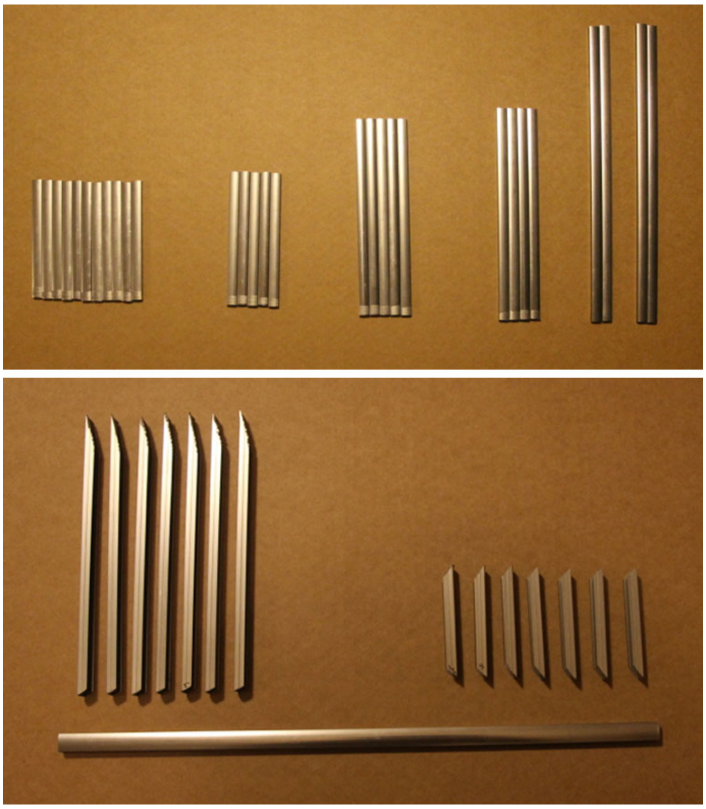

Figure 4.25 : The steel members

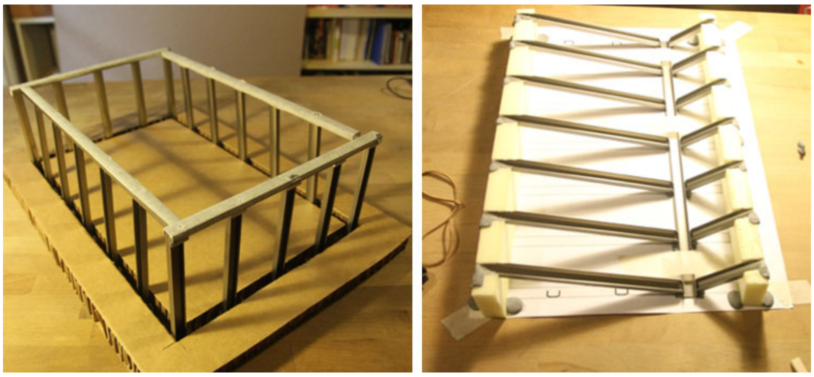

Figure 4.26 : The connection of the steel members

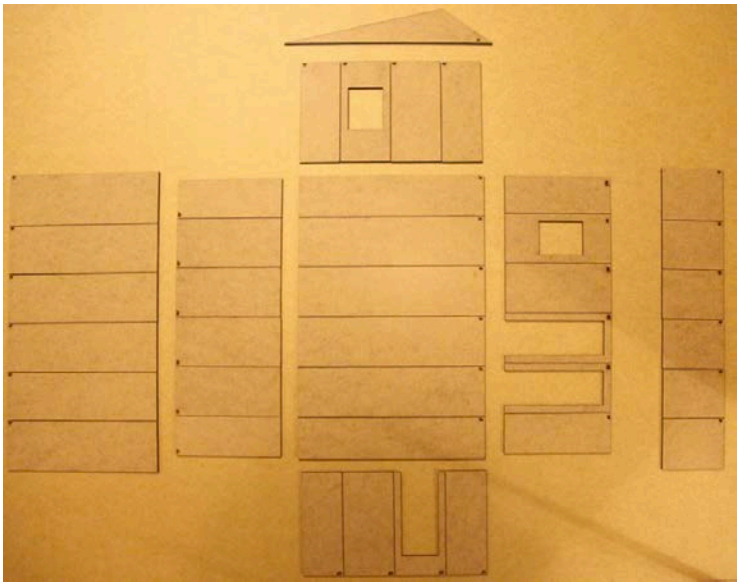

Figure 4.27 : Laser cut panels

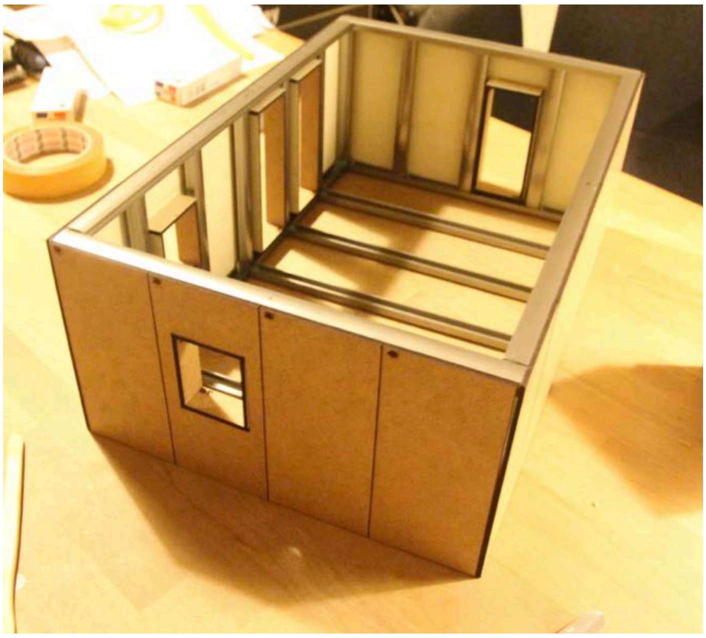

Figure 4.28 : The structure covered with panels

Figure 4.29 : The physical model

The prototype is a 1:20 model, made of 1,5cm steel profiles and 3mm plywood. One variation of the generated design from the 3D model was realized in a 1:20 scale model. The model measurements were extracted from the digital model and cut accordingly.

Structural elements were cut from aluminum profiles. An aluminum C profile of a 1.1mm thickness, 12mm height and 10mm width was chosen as the steel structure material to construct the model. The aluminum profiles were cut manually by the manufacturer in his atelier according to the bill of the structural elements derived from the generative model.

First, the columns were attached to the beams in order to create the frame of each surface of the model. In this phase, no adhesive or paste was used since the columns were impressed into the C profile beams with the help of rectangular 3 mm thick insertions. These impressions provided flexibility in locating the columns in their right position during the construction. In order to bring the four surfaces together and keep them attached while the paste get dry, a rectangular mold was prepared that wrap the surfaces from the exterior and compress them from the interior. The surface corners were fixed to each other with a resin adhesive since the model was too small to use bracket joints. The roof structure was similarly cut manually in the required size and bonded in a mold with the same resin adhesive.

The panel cladding shelling the model was 3mm thickness plywood. This material can be cut on a laser cutter and reflects the specifications of the 1 to 1 paneling material. The outside, inside and roof panels were extracted from the generative model and exported into AutoCAD in order to be transmitted to the laser cutter. A laser cutter with a 200 cm to 120 cm bed size was used. The panels were labeled according to their surface location and range, for example a1, a2, a3, … for outer panels and a1’, a2’, a3’, … for inside panels.

The panels were fixed to the steel structure with double side tapes. The outside panels were fixed first then the inside panels. The steel roof structure was placed at the top of the structure only after fixing all the vertical surface panels. Once the roof structure jointed to the rectangular frame, the roof panels were installed to finalize the model.

5. DESIGN DEFINITION: ADAPTABILITY & OPTIMISATION

This study contributes to the prefabricated post disaster temporary housing with a parametric approach. Providing an essential diversity for the post-disaster housing requirements has been the primary motivation of this study. Within this intention, the development of a model that involves the parameters and provides different prefabricated house designs has been one of the objectives of this study. Due to limited programing skills and the scope of a master thesis, this model initiates an experimental study, rather than a concluded generative tool to produce parametric prefabricated houses.

5.1. Evaluation of The Generated Model

Departing from the idea of answering to the post-disaster evacuees' needs and providing high level of comfort spaces for all, this research has built its question on how to embed different parameters into the temporary housing design within the existing prefabricated building system without increasing cost, construction time and labor. Simple assembly details are adapted for the generated digital model. This way, the construction of the generated prefabricated units needs no instruction, which requires similar labor qualifications and construction time as the conventional prefabricated houses. Since the material use and the labor cost are similar to the conventional prefabricated houses, it is possible to say that the developed model does not require extra cost, time or labor. However, the parametric model differs from the conventional prefabricated houses and develops a series of temporary houses that adapt to different sizes, climates, ground type and privacy.

It is possible for user to adapt the model in multiple ways, namely dealing with size of family in need, climatic requirements for the roof, and ground conditions for the foundation and privacy needs of the community. The parametric model can be modified in its size according to the number of users, in its section according to the climatic conditions, in its foundation according to the ground type and its privacy according to the plan scheme and paneling options. In this aspect, the model achieves an adaptive model of temporary prefabricated houses for the post-disaster dislocated people. Within this model the temporary house that meets the different requirement of adaptation and variety is decided and processes to be constructed. In view of that, it is possible to achieve temporary houses adaptable in term of size, climate, geography and culture.

This approach, by embedding variables such as family size, geographic and climatic conditions and privacy, is providing mass customization in the temporary house design. Mass production is not an option in architecture any longer with the digital modeling and fabrication technologies; in its stead, mass customization is affordable and fast. Designs, if modeled parametrically, can be adapted to any situation, precisely the post disaster construction. This thesis emphasizes this idea and provides a model to demonstrate it.

5.2. The Outcomes of The Fabrication & Model Making Process

The physical prototype was a small realization of the model in order to try out the production process. The 1:20 scale prototype includes both manual and digital fabrication and demonstrates the flexibility of the model in term of production. The generative model provides the user or contractor with the exact measurements and the number of elements required for construction. However, the ultimate goal is to reach a full digital prefabrication process in cases of post disaster resources may be limited and the flexibility of the model is essential.

In this project, the parametric model embeds parameters that provide variety in design. The model bridges the design to the construction phase at the same time by informing on the required material amount and dimensions to be prefabricated off site and fabricated on site. The assembly and disassembly of the structure and panels is important in this case and a fastening strategy is defined. The joints of components are all mechanical to provide for disassembly and reuse of components in case of other post disaster housing.

5.3. Contribution

This work points out the importance of variation and mass customization in the post disaster recovery process. By emphasizing the need of design and adaptability, it can contribute to the design of prefabrication housing industry not only after disaster but also in terms of variety and adaptation. The study may be expanded on different scales.

The model points out the necessity of simple, repetitive joint details in the post-disaster temporary housing construction. Improved designs that are also parametrically defined can be embedded to the digital model and optimize digital fabrication for more varied prefabricated designs.

The urban scale of the post-disaster housing communities stays as an open question. Strategies for how individual dwellings will form a functional and desirable settlement can be explored through more parameters and modeled digitally. Cellular automata for instance is a promising model in generating neighborhoods. The relation of each house with the other and the urban space they will define is important for increasing the physical comfort and feeling of neighborhood.

Finally, the model developed for this thesis can be advanced and shared open source. It can include more parameters or different structural systems and prefabricated materials. The model is open to adaptations and extensions.

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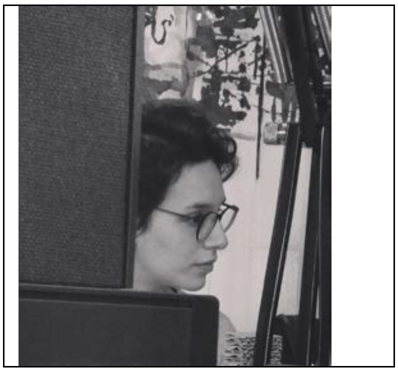
CURRICULUM VITAE



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