ISTANBUL TECHNICAL UNIVERSITY ★ GRADUATE SCHOOL OF SCIENCE ENGINEERING AND TECHNOLOGY

ARCHITECTURAL FORM EXPLORATION BY SOFT COMPUTING: THE CASE OF POST-DISASTER SHELTER

M.Sc. THESIS

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Department of Informatics

Architectural Design Computing Program

DECEMBER 2018

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ISTANBUL TEKNİK ÜNİVERSİTESİ ★ FEN BİLİMLERİ ENSTİTÜSÜ

ESNEK HESAPLAMA ARACILIĞIYLA MİMARİ BİÇİM ARAYIŞLARI: AFET SONRASI BARINAK ÖRNEĞİ

YÜKSEK LİSANS TEZİ

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Mimari Tasarımda Bilişim Programı

Tez Danışmanı: Dr. Öğretim Üyesi Sema ALAÇAM

ARALIK 2018

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Date of Submission : 1st November 2018
Date of Defense : 3rd December 2018

To the little ones of the family; Rüzgar, Ela & Ali…

FOREWORD

I would like to express my gratitude to my advisor Assist. Prof. Dr. Sema Alaçam who has always encouraged me with her positivity and guided me throughout this process despite the long distances between us. I am grateful to Assist. Prof. Dr. Michael Bittermann for sharing his expertise and broad knowledge in this particular field. I am thankful to my family for their support and for the trust they hold in me, to my friends for always being there for me and to my second home Daçka for making all this possible.

November 2018

Füsun Cemre Karaoğlan
Architect

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ABBREVIATIONS

CWW	**:** Computing With Words
EC	**:** Evolutionary Computation
FNT	**:** Fuzzy Neural Tree
GAs	**:** Genetic Algorithms
MOGAs	**:** Multi-objective Genetic Algorithms
NN	**:** Neural Networks
SC	**:** Soft Computing

ARCHITECTURAL FORM EXPLORATION BY SOFT COMPUTING: THE CASE OF POST-DISASTER SHELTER

SUMMARY

Soft Computing is composed of several computing paradigms that allows the incorporation of human knowledge and judgement into the digital environment. These methods are known to be permissive to imprecise concepts and partial truth, thus becoming quite applicable to architectural design problems. The major strengths of Fuzzy Logic and Neural Networks result in a learning system called Fuzzy Neural Tree which is transparent yet capable of dealing with medium complexity problems. In this thesis, the potentials of applying this newly developing method for an architectural design problem is searched and it is utilized as the main tool for a multi-optimization problem within a shelter settlement. Sheltering is one of the most crucial needs of humanity and every year many people are compelled to leave their homes due to disasters. Post-disaster shelters become a more critical subject of architectural design as the increasing number of natural disasters taking place each year, result in a larger number of people in need of urgent sheltering. When designing temporary shelters, it is a necessity to deal with the provision of materials, low-cost production and the time limit in the emergency as well as the needs of the users and the qualities of the space. Although computational approaches might lead much more efficient and optimal design solutions, they have been utilized in very few examples. For that reason in this thesis, computational tools are used throughout the conceptual design process. The study aims to create different configurations that satisfy the requirements of a post-disaster shelter. Towards this aim, *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint* and *Computational Design Process* are determined as the aspects to look for in a shelter design through the literature review. With the guidance of these aspects, previous shelter examples are analyzed and an algorithm that defines the growth pattern is constructed accordingly. A digital model is produced aiming to alter this algorithm as the pattern grows. These alterations are applied by Multi-Objective Genetic Algorithms and they perform towards satisfying the evaluation criteria within the Fuzzy Neural Tree. The struggle to define intangible architectural concepts for the evaluation of possible settlement scenarios holds potential for the further use of this particular method for architectural problems. Different from the previous studies, this thesis aims to focus on the design of a temporary shelter that can respond to different user types and disaster scenarios through mass customization, using an alternative methodology. While serving as a temporary space, the design outcomes are expected to create a more neighborhood-like pattern with a stronger sense of community for the users compared to the previous examples.

ESNEK HESAPLAMA ARACILIĞIYLA MİMARİ BİÇİM ARAYIŞLARI: AFET SONRASI BARINAK ÖRNEĞİ

ÖZET

SUMMARY

Esnek hesaplama insan yargısı ve bilgisini sanal ortamda uygulamaya olanak veren birçok farklı yöntemden oluşmaktadır. Bu yöntemler, belirsiz kavramlara ve kısmi doğruluk değerlerine karşı geçirgen olmaları sebebiyle hesaplamalı mimari tasarım örneklerinde sıkça kullanılmaktadırlar. Esnek hesaplama yöntemlerinden biri olan Bulanık Sinirsel Ağaç, Bulanık Mantık ve Yapay Sinir Ağlarının bir karışımıdır. Bahsi geçen her iki yöntemin de kuvvetli yönlerini alarak, transparan ancak orta karmaşıklıkta problemlerle baş edebilen bir yaklaşım ortaya çıkmıştır. Bu tezde, söz konusu Bulanık Sinirsel Ağaç yönteminin mimari tasarım problemi bağlamında potansiyelleri aranmakta ve bir afet sonrası barınak dokusunun çok amaçlı en iyilemesi için araç olarak kullanılmaktadır.

Barınma, insanın en temel ihtiyaçlarından biridir ve her yıl yaşanan çeşitli afetlerin sonucu olarak birçok insan yaşadıkları evleri, mahalleleri ve hatta şehirleri terk etmek zorunda kalmaktadır. Özellikle son yıllarda artarak yaşanmakta olan doğal felaketler, acil barınma ihtiyacı içindeki insanların sayısını artırmakta ve geçici barınakları giderek daha kritik bir tasarım ürünü haline getirmektedir. Afet sonrası tasarım süreçleri, zamanın kısıtlı olmasından, malzemenin tedarik edilmesine, üretim maliyetinin düşürülmesinden, geçici yaşam alanlarındaki mekan niteliğinin ve deneyiminin sağlanması gibi, çok boyutlu birçok bileşenden oluşmaktadır. Geleneksel tasarım süreci ile bütün bu farklı sorunlara eş zamanlı olarak çözüm üreten bir sonuca ulaşmak oldukça zorlayıcı olmaktadır ve geleneksel yöntemlerle tasarlanmış barınakların acil durumun gereklerine cevap verirken, kullanıcı çeşitliliğini ikinci planda bıraktığı görülmektedir. Dolayısıyla, böylesi karmaşık bir tasarım problemini bilgisayar destekli tasarım yaklaşımları yardımıyla çözümlemek, daha verimli ve bütünleşik bir süreç ortaya koyma potansiyeli taşımaktadır. Literatürde, afet sonrası tasarım süreçlerinde hesaplamalı tasarım araç ve yöntemlerinden yararlanan az sayıda proje yer almakla birlikte, bu çalışmalarda kullanılan yöntemlerin çeşitliliği, uygulanmış örneklerin sayısı henüz çok kısıtlıdır. Bu sebeple, bu çalışma kapsamında esnek hesaplama teknikleri kullanılarak afet sonrası kullanıma uygun bir yaşam alanı tasarlanması amaçlanmıştır. Literatür taraması sonucunda *Birimsellik, Esneklik, Gelişme Potansiyeli, Dijital Üretim, Kullanıcılar Tarafından İnşa Edilebilmesi, Küçük Karbon Ayakizi ve Hesaplamalı Tasarım Süreci* afet sonrası barınak tasarımıında aranacak özellikler olarak seçilmiştir. Afet sonrası barınak tasarımı örnekleri ve mevcut çalışmanın çıktıları bu özellikler çerçevesinde değerlendirilmiştir. Bu özelliklere yönelik olarak parça parça büyüyen ve bu süreçte büyüme algoritması çok amaçlı optimizasyon aracılığıyla şekillenen bir sistem tasarlanmıştır. Değerlendirme kriterleri Bulanık Sinirsel Ağaç aracılığıyla inşa edilmiş ve çok amaçlı optimizasyon

sürecine dahil edilmiştir. Çalışmanın özgün katkısı, bu güncel yöntemin afet sonrası tasarım sürecine dahil edilmesi ve çoklu optimizasyonun doğrudan büyüme algoritmasını değiştirebilmesidir. Bu sayede, hem kullanıcı odaklı hem de acil durum koşullarına bir arada cevap olabilecek bir sonuca ulaşılabileceği öngörülmektedir.

Proje kapsamında öncelikle afet sonrası yaşam alanları konusunda bir genel bakış sunulmaktadır. Birçok örnekte görüldüğü gibi her yıl çok sayıda insan doğal felaketler sebebiyle geçici barınaklarda yaşamak zorunda kalmaktadırlar. Her ne kadar rehabilitasyon döneminde inşa edilen barınakların yalnızca kalıcı konutlar inşa edilene kadar hizmet etmesi planlansa da, bu geçici yaşam alanlarında depremden sonra yıllarca yaşayan ailelerin olduğu görülmektedir. Dolayısıyla, barınaklar özellikle gelişmekte olan ülkelerde neredeyse kalıcı bir konuttan beklenen görevi üstlenmekte ve uzun yıllar özel olarak tasarlanmadığı ve uygun olmadığı bir işleve hizmet etmektedir. Dolayısıyla, gelecek yıllarda üretilecek olan geçici yerleşimlerin *Birimsellik, Esneklik, Gelişme Potansiyeli, Dijital Üretim, Kullanıcılar Tarafından İnşa Edilebilmesi, Küçük Karbon Ayakizi ve Hesaplamalı Tasarım Süreci* özelliklerini taşıması beklenmektedir. Bu özellikler, devamındaki bölümler için bir altyapı oluşturmaktadır.

Esas olarak yöntemin öne çıktığı bir çalışma olması seebebiyle Esnek Hesaplama yöntemlerinin mimari tasarım bağlamında uygulamarı incelenmiştir. Sinirsel Bulanık Ağlar, Yapay Sinir Ağları ile Bulanık Mantık Teorisinin birleşerek oluşturduğu bir sistemdir. Bu sistem çerçevesinde ele alınan Bulanık Sinirsel Ağaç, Bulanık Sinir Ağlarına benzer özellikler taşımaktadır ancak sitemin inşası katmanlarla değil, bu katmanların içindeki sinirlerin teker teker birleştirilmesiyle yapılmaktadır. Bu şekilde Yapay Sinir Ağlarının kara kutu modelinden uzaklaşarak daha geçirgen ve esnek bir sinir yapısına ulaşmak mümkün olmaktadır. Sözkonusu sinirsel ağacın Bulanık Mantık ögelerini barındırması, kısmi doğruluk değerleri ve sözel tanımlar barındıran belirsiz bilimler ile bir arada kullanılmasına olanak sağlamaktadır. Bu şekilde, mimari bir yapının değerlendirme kriterlerinin inşasında Bulanık Sinirsel Ağaç kullanımı çok amaçlı optimizasyonun daha başarılı sonuçlanması konusunda yardımcı olmaktadır. Bu çalışma, afet sonrası koşullarda kurulacak bir yaşam alanının büyüme algoritmasının, Çok Amaçlı Genetik Algoritmalar tarafından, Bulanık Sinirsel Ağaç aracılığıyla inşa edilmiş uygunluk fonksiyonlarına yönelik olarak değerlendirilirken geliştirilebilecği hipotezine dayanmaktadır. Uygulanmış örneklerde görülen, tek bir modelin tekrarlanmasıyla üretilen bir yaşam alanının aksine, bu çalışmada söz konusu yöntem aracılığıyla farklılaşan birimlerden büyüyen bir sistem tasarlanmıştır.

Uygulama yapılmadan önce, literatürde bulunan afet sonrası yaşam alanı örneklerinin bir kısmı seçilmiş ve bu örnekler *Birimsellik, Esneklik, Gelişme Potansiyeli, Dijital Üretim, Kullanıcılar Tarafından İnşa Edilebilmesi, Küçük Karbon Ayakizi ve Hesaplamalı Tasarım Süreci* çerçevesinde incelenmiştir. Her bir örneğin öne çıkan yönleri ve bunların nasıl sağlandığı belirlenmiştir. Bu sayede, uygulama aşamasında algoritma belirlenirken daha kuvvetli bir yol izlenebilmektedir

Tasarım sürecinde öncelikli olarak yaşam alanını oluşturacak birim çeşitleri tanımlanmıştır. Islak mekan, yaşam mekanı, kişisel mekan ve açık mekan birimleri bir araya gelerek bir ailenin yaşam modülünü oluşturmaktadır. Daha sonrasında ise sistem birim birim büyümeye devam ederek birkaç yaşam modülünden oluşan bir örüntü ortaya çıkarmaktadır. Bu aşamada birimlerin bir araya gelişlerini belirleyen adımların tanımlanması gerekmektedir. Ardından yerleşimin dokusunu oluşturan her bir adım Grasshopper ortamında, çok amaçlı genetik algoritmalara parametre olarak

tanımlanmaktadır. Birim birim büyüyen örüntü, ortaya binlerce farklı ihtimali koymaktadır. Bu seçeneklerin her bir değişimde çok amaçlı genetik algoritmalar tarafından değerlendirilmesi, tüm arama uzayını taramaya gerek kalmadan en iyilenmiş sonuçlar elde edilmesini sağlayacaktır. Genetik algoritmaların örüntüleri değerlendirebilmesi ve aralarından seçim yapabilmesi için öncelikle uygunluk fonksiyonlarının tanımlanması gerektmektedir. Bu aşamada uygunluk fonksiyonlarının bir kısmı daha önceden seçilmiş olan *Birimsellik, Esneklik, Gelişme Potansiyeli, Dijital Üretim, Kullanıcılar Tarafından İnşa Edilebilmesi, Küçük Karbon Ayakizi ve Hesaplamalı Tasarım Süreci* özellikleri ve bir kısmı da sezgisel mimari kararlar baz alınarak belirlenmiştir. Değerlendirme aşamasında, hedeflenen ölçütleri sağlamaya yönelik olarak parametler değişikliğe uğratılarak çıktılar puanlanmaktadır. Bu aşamada girdilerini modelden alarak, Çok Amaçlı Genetik Algoritmalar tarafından değerlendirilecek sonuçları üreten Bulanık Sinirsel Ağaç inşa edilmektedir. Bu ağacın sinirlerini bulanık mantıkta kullanılan "VE" ve "VEYA" operatörleri oluşturmaktadır. Operatörlere girdi olarak, model üzerinden tanımlanan ve hesaplanan değerler sağlanmaktadır. Bu değerler 0 ile 1 arasında değişen doğruluk değerleridir ve uygunluk fonksiyonuna göre hesaplanmaktadır. Söz konusu çalışmada, bulanık sinirsel ağın iki ana çıktısı performans ve mimari niteliktir. Mimari nitelik açık alanların devamlılığı ve modüller arası komşuluk ilişkileri baz alınarak hesaplanmaktadır. Performans kriteri ise yaşam alanlarında doğal aydınlatma, kütlenin sıkılığı ve ayak izinin alanı üzerinden tanımlanmaktadır. Bütün bu değerler Bulanık Sinirsel Ağaç üzerinden aktarılarak Çok Amaçlı Genetik Algoritmaların uygunluk fonksiyonunu oluşturmaktadır. Değerlendirma aşaması sonucunda sekiz farklı birbirine baskın olmayan örüntü elde edilmiştir ve bir tanesi seçilerek tekrarından oluşan bir afet sonrası yaşam alanı örneği sunulmuştur. Bu örnek değerlendirildiğinde, *Birimsellik, Esneklik ve Hesaplamalı Tasarım Süreci* özellikleri başarıyla entegre edilmiştir. *Gelişme Potansiyeli, Dijital Üretim, Kullanıcılar Tarafından İnşa Edilebilmesi* ve *Küçük Karbon Ayakizi* özelliklerinin inşaat ve detaylandırma süreçlerinin daha derinleşmesi sonucunda kesin olarak tasarıma katılabileceği düşünülmektedir. Sonuç olarak, Esnek Hesaplama bu çalışmada afet sonrası yaşam alanı tasarımında kullanılmış ve başarılı sayılabilecek bir şekilde sonuçlanmıştır. Hesaplamalı tasarım bu bağlamda yüksek potansiyele sahip bir araç olarak, zorlu ölçütlere maruz kalınan afet sonrası koşullarında bile mimari niteliği ve performansı yüksek ürünlerin elde edilmesinde kullanılabileceğini kanıtlamıştır.

Sonuç ürününün, başta İstanbul depremi olmak üzere bölgede yaşanacak bir afet halinde ortaya çıkacak acil barınma ihtiyacına cevap olacak seçeneklerden biri olması hedeflenmektedir. Çalışma ilerleyen zamanlarda detaylanarak çeşitli prototipler üzerinden denenebilir ve belirlenen özelliklerin tümüne cevap veren alternatifler üretebilir. Daha sonraki aşamalarda, henüz yalnızca mimari biçim arayışı ve yöntem denemesi olan bu çalışmanın bütünleşik bir sisteme evrilerek, kavramsal tasarım aşamasından, dijital üretim yöntemlerini içeren bir uygulamaya kadar uzanan bir modele dönüşmesi amaçlanmaktadır.

1. INTRODUCTION

Soft Computing (SC) is a collection of several computing paradigms which are known to be permissive to imprecise concepts and partial truth. Their harmonious mixture enables a system that allows the incorporation of human knowledge and judgement into the digital environment (Jang et al., 1997), thus making these methods quite applicable to architectural design problems. One of these methods named as Fuzzy Neural Tree (FNT) is a hybrid of Fuzzy Logic and Neural Networks. The major strengths of these two methods result in a transparent learning system which is yet capable of dealing with medium complexity problems (Ciftcioglu and Bittermann, 2015). In this thesis, the potentials of applying this newly developing method for an architectural design problem is searched and it is utilized as the main tool for a multi-optimization problem within a shelter settlement. When constructing shelter settlements in a post-disaster context only the basic needs of the users are considered, thus putting architectural quality in the back of the long line of requirements. However, through the use of a computational tool for this particular design problem can be solved much more efficiently. With this in mind, the aim of this thesis is to utilize Fuzzy Neural Tree within the multi-optimization process of the layout generation of a shelter settlement. Towards this aim, the aspects to look for in a shelter design are determined through the analysis of the selected examples and with the guidance of these aspects modular settlement possibilities are generated. Original contribution of this study is that it focuses on the use of an alternative methodology for the design of a disaster relief shelter and constructs a system where Multi-Objective Genetic Algorithms control the growth of the mass whilst evaluating it. Also, the struggle to define intangible architectural concepts for the construction of the FNT within the evaluation phase holds potential for future studies. The results are expected to present several different post-disaster living space configurations that are able to satisfy the needs of the users as well as emergency requirements.

This thesis, starts with an overview of the major problems and the main concepts in disaster relief shelters in order to determine the crucial aspects within the design of a

shelter. Then, the methodology and its application within architectural design are presented to understand the potentials of this particular tool. Next, selected disaster relief shelter examples are analyzed with the guidance of the aspects chosen in the first chapter. Last, the case study is explained in detail where all these selected aspects and the application of FNT overlap each other, resulting in several different shelter settlement configurations.

1.1 Major Problems in Disaster Relief Settlements

Sheltering is one of the most crucial needs of humanity and every year many people are displaced due to various reasons such as "natural disasters, famine, development and economic changes." (O'Keefe, 2017). In a report that bases its research upon displaced people, it is stated that "Since 2008, an average of 26.4 million people per year have been displaced from their homes by disasters brought on by natural hazards. This is the equivalent to one person being displaced every second." (IDMC & NRC, 2015). As the increasing number of disasters taking place each year result in a larger number of people in need of urgent sheltering, temporary shelters become a more critical subject of architectural design.

Most often shelters have to respond to a sudden increase in demand thus putting the provision of materials, low-cost production and the time limit in the emergency in front of the architectural quality (Abulnour, 2014). The built examples mostly consist of repetitive units without any differentiation from one another. As a result, many people from many different social attributes and backgrounds are compelled to dwell in identical spaces. When considering that shelters are built temporarily, usually for short periods, this problem might seem to be insignificant. However, in some cases where the provision of permanent housing is challenging, temporary shelters are used for a much longer time than they are supposed to. For instance, in one of the previous examples, shelters that were designed to serve for 1-2 years within a post-disaster rehabilitation phase were accommodated up to 30 years (Gümüş, 2000). Also, in a report, it has been stated that permanent housing reconstruction can take up to 5 years in certain cases (FEMA, 2005, Figure 1.1). As proven by experience, shelters may have to uphold the requirements of a permanent house and serve a purpose that it was neither designed nor appropriate for. Therefore, in the upcoming cases, it is crucial for temporary living spaces to be more flexible in terms of service periods and user types.

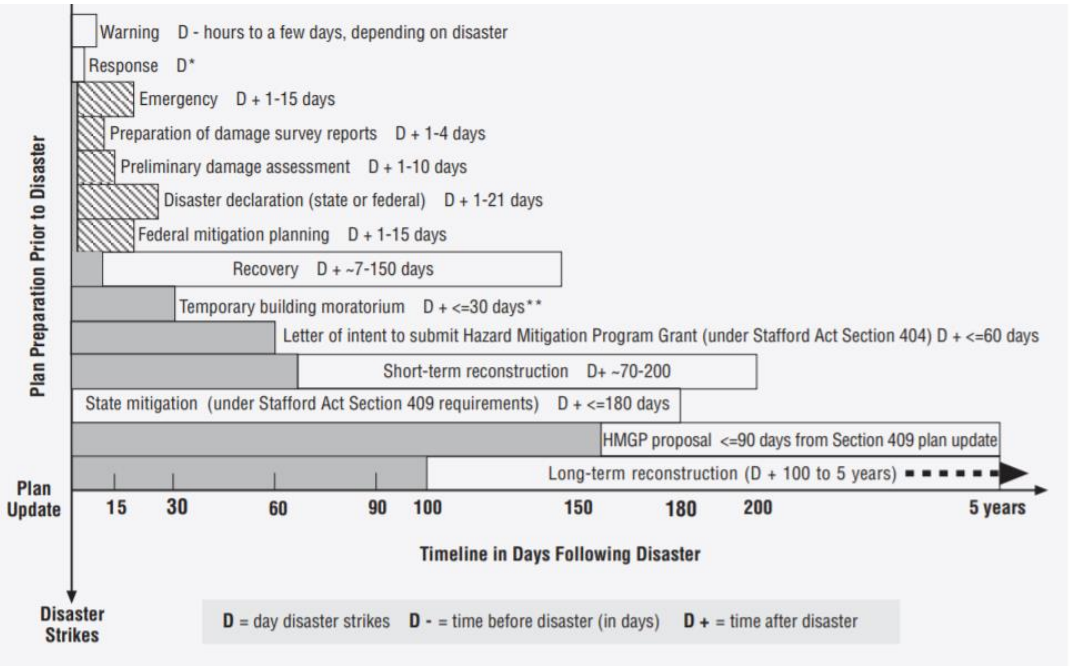


Figure 1.1: Post-disaster reconstruction timetable (FEMA, 2005, p.92).

There are several reasons for families to stay in temporary shelters than the intended period. One of them is the constant decrease in the "social welfare" of the families that used to pay rent instead of owning a house. For instance, in the aftermath of the earthquake in 1999 in İzmit, the government only provided permanent housing for the homeowners who could prove that their house collapsed (Arslan and Ünlü, 2008). So, it may have been more convenient for families to keep living in the temporary settlements for a longer period as they would have to pay rent otherwise. Also, it becomes more challenging to get support for the reconstruction period as the media and public attention drops gradually within a year after the incident (Arslan and Ünlü, 2008). Therefore, the families can be having a hard time finding enough aid to assist them through the moving process from temporary settlements to permanent ones.

Today, the design of a disaster relief shelter and providing a secure space through the aftermath of a catastrophe is not considered a vital issue until the disaster itself is encountered. It has been observed that in most cases that the efficiency of the designs has not reached its full potential (Bashawri et al., 2014). Therefore, analyzing the previous examples is a requirement to get past the existing problems and to reach an optimized solution. In addition, it is a necessity to document the research on the matter in order to understand the position of this study within the literature.

One of the most crucial aspects that shelters lack is sense of ownership. Almost all of the built examples have been the repetition of identical units that offers no

differentiation from one user to another. When the way users interact with their surroundings is observed, it can be seen clearly that identical units do not satisfy the needs of the inhabitants. In one of the research based on Yeniköy-Kocaeli temporary settlement, it is seen that only %19 of the residents have not made any changes in their units (Figure 1.2).

Figure 1.2: Changes made by the users (Şener and Altun, 2009, p.61).

Alterations have taken place outdoors and indoors in %48 of the cases and they have taken place only outdoors in %30 of the cases (Şener and Şener, 2003).

The aforementioned research clearly shows the significance of customization within the units and it proves the necessity of a higher quality architectural design even for temporary shelters. When displaced people are compelled to live in these settlements for several months or years, they feel the need to make modifications in and around the units. If these modifications were foreseen and the structures were flexible enough to allow participation during or after the construction process, then the sense of ownership would have been much stronger. This *Flexibility* can be achieved by allowing small changes for each unit during the design process. In this way, the main problem of repetition can easily be avoided and every unit can be slightly different than the other, creating more customized, personalized, higher quality spaces. Therefore, *Flexibility* can be listed as the main aspect to satisfy for a construction within a post-disaster context.

When designing disaster relief shelters, it is a necessity to deal with the provision of materials, low-cost production and the time limit in the emergency as well as the needs of the users and the qualities of the space. With this in mind, computational approaches might lead much more efficient and optimal design solutions when a post-disaster scenario is in the centre of the question. "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." (Rezoug, 2013). As post-disaster construction is a multi-layered problem with several contradicting parameters to satisfy, the process to be much faster and optimized with the aid of a computational tool. Most of the post-disaster settlements are designed, manufactured and assembled manually (Şener and Altun, 2009; Salvalai, 2017) which may cause the whole process to be inadequate under post-disaster conditions. Therefore, creating an automated and possibly holistic design, fabrication and construction processes can be much more effective. Therefore, the aspects that present themselves to be crucial within the design of a shelter settlement are the use of a *Computational Design Process* and whether it is connected to a *Digital Fabrication* tool for the pre-fabrication of construction elements. In addition, in an emergency, it is expected for a structure to be assembled in a very short time and with limited external help (IFRC/RCS, 2013). Therefore, the inhabitants should be able to construct the whole structure by themselves without the help of a technical authority or assembly. So, whether or not it is a *Construction* that can be done *without External Help* is another requirement to look for when designing a shelter. An aspect to support the ease of construction and a crucial element for disaster relief construction is *Modularity*. A settlement or a unit made up of repeating elements can provide much more *Flexibility* within the design process and make the fabrication and construction phases much more efficient. Modular structures are most often easier to assemble – disassemble, store and transport. Furthermore, these settlements are not permanent structures and they are demolished if not relocated. So, it is a necessity for these structures to leave the smallest possible trace behind and to be constructed with reused or reusable materials. They can either be using an otherwise wasted material or can be disassembled when needed. Therefore, an aspect to underline can be *Small Carbon Footprint* when examining a shelter example.

1.2 Concepts Related to Disaster Relief Settlements

When designing a shelter rather than a permanent house, architectural concepts incorporate new vocabulary as the construction phase takes place within an emergency phase. Even though the concepts are assumed to be self-explanatory, they are defined in several different ways within the literature. In regards to that, a related terminology is going be discussed and their relevance to the study is going to be clarified.

House and shelter are the first two terms that need to be defined before going deeper into sub-categories. One definition is that they are two parts of an ambiguous relationship where they indicate the "point of time reference in a disaster life cycle from the appearance of a threat to the return back to normal routine activities in the community." (Quarantelli, 1991). In addition, the shelter is defined as "Secure habitable covered living space providing privacy and dignity for those within it." (IFRC, 2010).

Several researchers have worked on categorizing types of post-disaster settlements according to their functions and estimated periods of service. There are two major categorizations related to post-disaster living spaces. The first one is the widely accepted classification by Quarantelli (1991) and the second one is the classification presented by IFRC/RCS (2013) many years later.

Quarantelli has defined four different types of shelter/housing:

- Emergency Shelter (first 72 hours): A place where individuals stay right after the emergency. An organization is not required as it is usually a temporary individual effort.
- Temporary Shelter (first 60 days): A place other than one's own where they can obtain their food.
- Temporary Housing (first year and beyond): A place where displaced populations are accommodated and daily routines are slowly resettled until the permanent houses are completed. Access to water, electricity, heating is ensured.
- Permanent Housing: Reconstructed spaces for long-term usage.

IFRC/RCS (2013) has defined another categorization, further sub-dividing some of the previous components (Figure 1.3):

- Emergency Shelter: Provides life-saving support, used right after the disaster for a brief time.
- Temporary Shelter: Easily built, low-cost, reusable shelter types. May have a shorter span of life in order to satisfy these criteria.
- Transitional Shelter: Upgradable shelters in terms of construction location or materiality. Quickly built and may have to be set up by the users themselves.
- Progressive Shelter: Upgradable to permanent structures in terms of structural property and detailing.
- Core Shelter: First part of a permanent housing. Small initial solution but can grow into a bigger space.
- Permanent Housing: Reconstructed spaces for long-term usage.

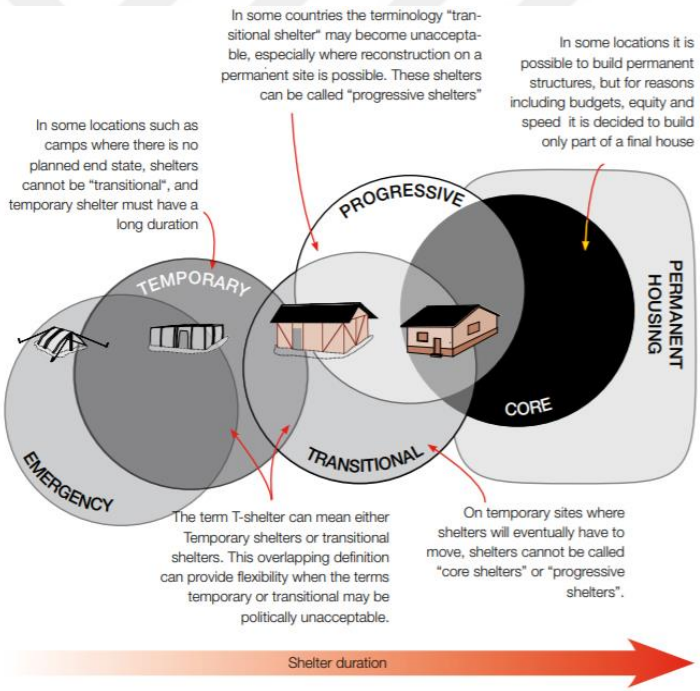


Figure 1.3: Overlapping stages of post-disaster relief structures (IFRC/RCS, 2013, p.9).

In this study, the living space is expected to have a transformable character in order to be able to adapt to the changing periods of service. Because, one of the biggest problems in post-disaster settlements in Turkey is the lack of sustainable solutions where a temporary shelter can be transformed into a more transitional or progressive one in time (Limoncu and Bayülgen, 2008). Therefore, *Upgrade Potential* presents itself as another aspect to be satisfied in a post-disaster construction. In this thesis,

the second categorization by IFRC (2013) correlates better to the main objective. Therefore, the design in the case study can start to function as a temporary shelter and change itself through materiality and size to become a transitional shelter. So in this project, the living space designed can be classified as a T-shelter, which is defined as the general term referring both temporary and transitional shelters (IFRC/RCS, 2013).

To sum up, an overview regarding post-disaster construction is presented in this section. The main focus has been, summarizing the main problems and concepts related to disaster relief settlements. Through this overview, the aspect to satisfy when designing a post-disaster shelter have been listed as *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint* and *Computational Design Process.* These aspects can later serve as key points to look for in the previous examples and the case study in this thesis.

2. SOFT COMPUTING IN ARCHITECTURAL DESIGN

Soft computing (SC) is a branch of Artificial Intelligence and it is composed of different methods that are known to be permissive to imprecise concepts and partial truth. It is a collection of several computing paradigms such as neural networks, fuzzy set theory, approximate reasoning and optimization techniques such as genetic algorithms. Their harmonious mixture enables a system that somehow allows the incorporation the human knowledge and judgement into the digital environment (Jang et al., 1997). It has come into prominence due to its varying field of application where hard optimization techniques can fall short (Emel ve Taşkın, 2002). It is categorized into three main titles as Neural Computation, Evolutionary Computation and Fuzzy Techniques (Salcedo-Sanz, 2014, Figure 2.1).

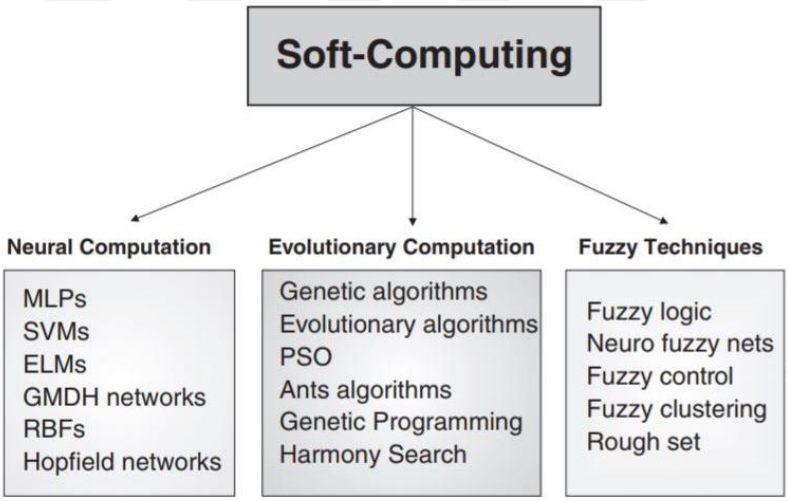


Figure 2.1: Branches of Soft Computing (Salcedo-Sanz, 2014, p.2).

Soft computing has been used in the context of architectural design in a lot of different studies with varying methods (Figure 2.2). It is one of the most widely used methods in the field of computational design as it can serve as a major decision making tool in the conceptual design process. In this study, a hybrid methodology that combines Genetic Algorithms (GAs) and Neuro-Fuzzy Networks is chosen to be applied in the design process of a post-disaster shelter.

Methodology	Strength
Neural network	Learning and adaptation
Fuzzy set theory	Knowledge representation via fuzzy if-then rules
Genetic algorithm and simulated annealing	Systematic random search

Figure 2.2: The strength of different techniques that constitute SC (Jang et al., 1997, p.2).

2.1 Evolutionary Computation

The field of Evolutionary Computation (EC) has a history that goes all the way back to 1950s, but it started to attract a wider audience as its applications varied and spread. Genetic Algorithms (GAs) is one of the most widely used systems within EC. It has been developed by John Holland who specialized in Psychology and Computer Science. He came up with the notion of GAs through his efforts to apply the genetic process that living organisms go through in a digital environment (Kurt and Semetay, 2001). ”These algorithms typically use an analogy with natural evolution to perform a search by evolving solutions to problems.” (Bentley and Corne, 2001, p.5).

2.1.1 Single-Objective Genetic Algorithms

The main concepts relate to GAs are genotype, phenotype (Figure 2.3). Each and every trait that defines the properties of an individual is called a gene. They are the instructions for building an organism. Genes come together and form a sequence, creating a chromosome or in other words a **genotype.** Genotypes are the abstract representations of candidate solutions which are called **phenotypes**. Much like in a living organism, genotype is the description of a possible solution to the problem whereas phenotype is the candidate solution itself (Matuzsek, 2006).

Some of the reasons for GAs to be as popular as they are today, are their efficiency in obtaining optimized results within short periods of time and their ease of use. Within the optimization process they do not require to scan the whole search space, so they can come up with an optimal solution in a short amount of time. All sorts of problems can be solved quite easily with the aid GAs if it is provided with two main elements: An objective function and the variable within the problem. An objective function is all that it takes to inform GAs about the better option and to give a direction for the system

to work towards whilst altering the variables (Goldberg, 1989). “GAs can tackle optimisation problems if these problems are formulated in terms of search, where the search space is the space containing all possible combinations of parameter values, and the solution is the point in that space where the parameters take optimal values.” (Bentley & Wakefield, 1995, p.1). Every chromosome has a fitness function that is evaluated according to the objective function defined. The options with a “better” fitness are transferred to the next generation (Figure 2.4).

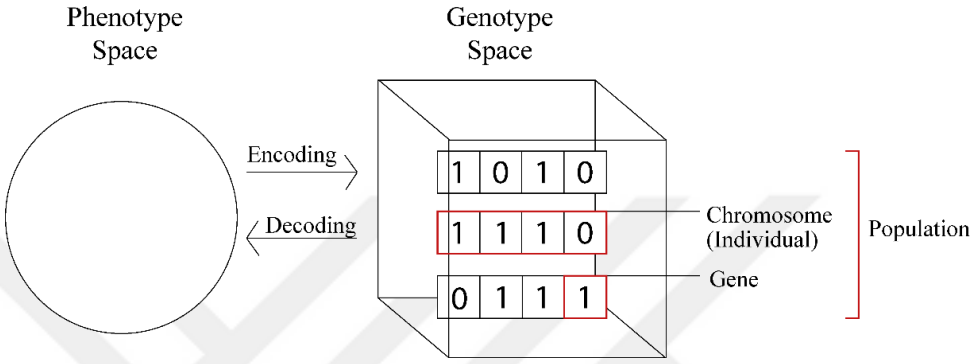


Figure 2.3: Phenotype and Genotype concepts.

GAs function in an iterative manner and basically includes the following steps (Emel ve Taşkın, 2002):

- All the possible solutions in the search space are encoded into chromosomes.
- A pool of individuals is created randomly according to the desired population size.
- These individuals are scored according to the fitness function.
- Some of these individuals are mated to produce new offsprings.
- Evolutionary operators such as crossover and mutation are applied to the diversity within the pool.
- Repeating the previous steps until reaching the maximum number of generations.

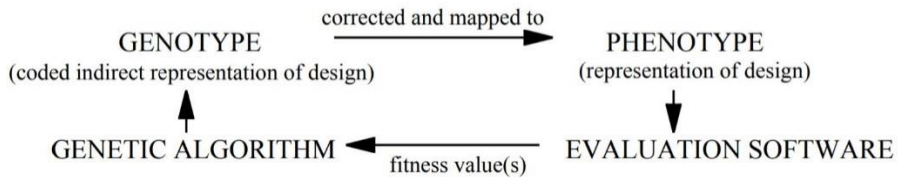


Figure 2.4: A diagram representing the elements of GA (Bentley & Wakefield, 1995, p.2).

In a study conducted by Bentley & Wakefield (1995), GAs are used in the design of a table. Their hypothesis is that GAs can work further than solemnly to optimize a design and create novel solutions to a design problem. The primitive shapes are controlled by GAs through the variables and they are put together in different configurations to be evaluated each time. They are evaluated based on several different fitness functions such as size, mass, unfragmented design, stability, flat surface, and supportiveness and stability. The researchers conduct varying experiments, changing an aspect such as the generation GAs are stopped each time (Figure 2.5). The results turned out to be a confirmation of their hypothesis that GAs can work with design tasks and result in meaningful solutions.

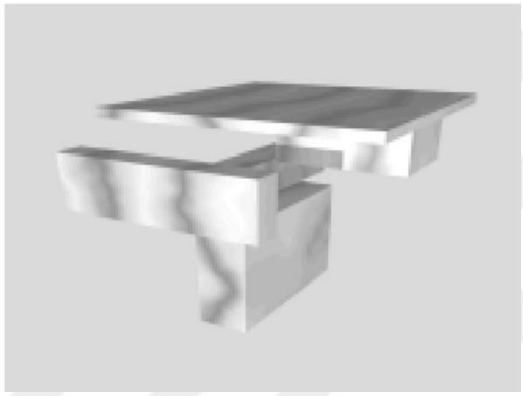


Figure 2.5: "Experiment 1: evaluating size, low mass, stability and flat top" (Bentley & Wakefield, 1995, p.6)

2.1.2 Multi-Objective Genetic Algorithms

Even though single-objective optimization can be useful in many fields, most of the optimization problems that take place in the real-world have multiple objectives that contradict each other. In order for it to be applied in a single objective optimization system, all objectives are scalarized into a single one in order for GA to work towards and the outcome is one optimal solution. When this is the case, the user cannot decide on the degree and selection of compromises made. As there are multiple contradicting objectives, the options that lie on predominantly one objective or another fade within the evaluation process and the outcome does not present any information regarding these Pareto-optimal solutions (Deb, 2014). However, with the development in the field it has become possible for GA to work with multiple objectives simultaneously and present all the non-dominated solutions located on Pareto-optimal front. Multi-objective genetic algorithms (MOGAs) have proven themselves to be much better

tools than single-objective genetic algorithms when the case is a multidimensional problem. Therefore, MOGAs present themselves to be a strong option for the evaluation phase in this thesis.

Initially, the aim of the study was generating 2D rule-based layouts and then assessing the outcomes with the aid of MOGAs. So, a set of plan layouts would be designed and the best options would be selected. However, with that methodology assessing large numbers of options one by one would not be an efficient solution. It would be much more useful for GAs to use the rules as its parameters and alter them while evaluating the outcomes.

In one of the studies the term "Shape Evolution" has been used to describe a similar methodology. Chouchoulas (2003) defines shape evolution as "An algorithmic method for conceptual architectural design combining shape grammars and genetic algorithms". So, shape evolution is a two-step process where a rule-based shape is evaluated and evolved through items. The genetic algorithms use the rules of the shape grammar as a genotype, changing them to reach the objectives of the project. It aims to serve as a tool in the conceptual phase of architectural design, as it can answer to the objectives of an architectural project in the design language of a certain architect. Firstly, the basic rules that form the shape grammar are determined which are only three in the case study by Chouchoulas (2003) (Figure 2.6). Then, through the use of genetic algorithms, outcomes of the rules are evaluated and then altered according to its proximity to the fitness functions. The outcomes that scored the maximum are presented (Figure 2.7).

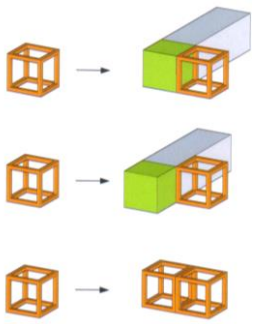


Figure 2.6: Three main rules (Choucoulas, 2003, p.47).

Considering EC to be much more applicable for a design brief where function plays a more important role than form is a frequent assumption (Ängeslevä, 2001). However, using GAs as an EC technique alongside the principles of Fuzzy Logic can result in a

much more hybrid and successful solution, especially when the case is architectural design.

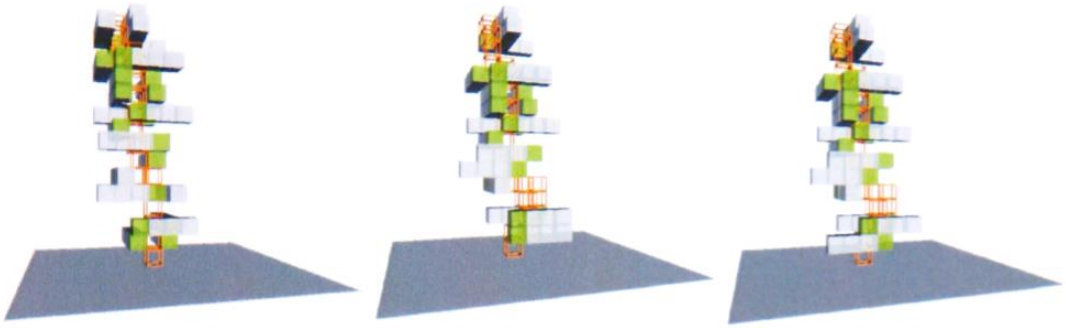


Figure 2.7: Tower designs with maximum scores (Choucoulas, 2003, p.74).

2.2 Fuzzy Methods

2.2.1 Neural Networks

Neural Networks (NN) are algorithmic metaphors of the human nervous system in that they consist of simple computational units, called neurons, interconnected based on a sheer amount of diverse topologies. They bear a lot of potentials as they are theoretically proven to approximate any mathematical function mapping descriptive inputs to desired outputs provided an adequate network topology is chosen. They are particularly attractive as the steps of the process are not determined manually by programmers (Yegnanarayana, 2009). There are many studies investigating the cognitive processes of human judgment and aiming to artificially produce it. NN are considered to be one of the most widely used tools for that purpose. Neurons are the most basic elements of NN (Figure 2.8). They interpret the signals that reach them by multiplying them with the calculated weight and transferring the output to the next neuron if there is any (Fullér, 1995).

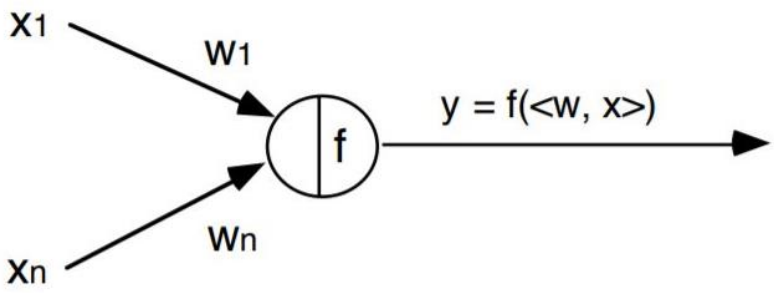
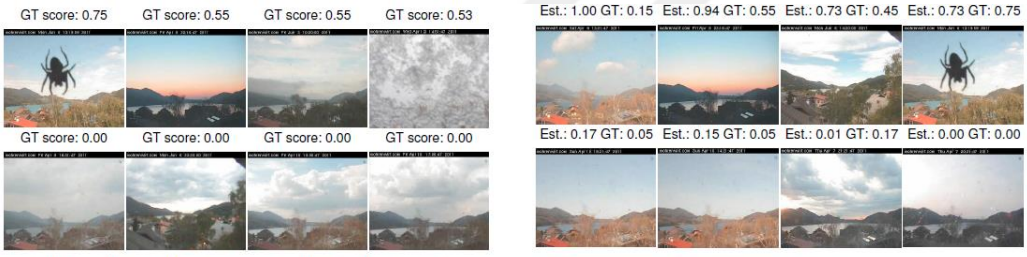


Figure 2.8: A simple Neural Network structure (Fullér, 1995, p.7).

Several studies strive to measure the aesthetics of photographs and to use it as a factor in sorting out the results in search engines. For this purpose, features such as color, texture, composition, and content, which are thought to have a role in visual aesthetics, are usually manually selected. In many of these examples, the concept of aesthetics is questioned in terms of the art of photography. Datta et al. try to identify the attributes that are making photos aesthetically appealing by selecting attributes from hundreds of images downloaded from Photo.net (2006). Even though they take a different approach in terms of methodology, their struggle to measure aesthetics is in a parallel direction with the concern of measuring intangible concepts in this research. In a similar study by Gygli et al.(2013), a database of photographs are analyzed through selected features and they try to determine the underlying attributes making photos interesting. As a result of the research, they manage to create an algorithm that ranks photos similar to that of people, according to their interestingness level (Figure 2.9).



(a) Human labeling. **Top:** most interesting **Bottom:** least interesting.

(c) Predicted interestingness. **Top:** most interesting **Bottom:** least interesting.

Figure 2.9: Interestingness in photographs ordered by human subjects *(left)* and by Neural Networks *(right)* (Gygli et al., 2013, p.1637).

Although the central topic and the methodologies of the three studies mentioned above are completely different to the one in this study, the struggle to define fuzzy concepts within a digital environment resembles the one in this thesis. Therefore, the use of a neuro-fuzzy system can be much more efficient regarding in the context in question.

2.2.2 Neuro-Fuzzy Systems

Neuro-Fuzzy Systems or a Fuzzy Neural Networks are learning systems that unite approximation techniques of neural networks with the ability of fuzzy sets to deal with the partial truth.

Still today, there is a big need for computational methods dealing with soft subjects (Zadeh, 2012). Fuzzy logic is one of the strongest approaches in integrating verbal judgement with computing systems and it is basically “Computing With Words”

(CWW) as Zadeh (1996) describes. “In essence, CWW is a system of computation in which the objects of computation are words, phrases and propositions drawn from a natural language. The carriers of information are propositions.” (Zadeh, 2012, p.4). It is a strong hybrid of natural languages and computation with fuzzy variables thus making it one of the strongest methods within the computational approaches regarding soft subjects (Zadeh, 2012). A study that works with applying Fuzzy Logic principles in an architectural context works with the analysis of a site plan. It evaluates each house on an existing site plan with a system based on verbal expressions such as “close to the underpass” or “far from the underpass” (Çekmiş, 2016, Figure 2.10).

Figure 2.10: The scores of the houses on the site plan after the analysis (Çekmiş, 2016, p.181).

Although both NN and Fuzzy Systems are used for the studies regarding Soft Computing, they have major differences. NN is specialized in working with high complexity and heavy loads of data, where Fuzzy Logic is only capable of dealing with low complexity problems. So, Neuro-Fuzzy Systems are much more adjusted to a medium complexity level. NN is a black box system, so it is not possible to extract information about the ongoing process within the input and output and it is not possible to control the learning process. However, Fuzzy Logic is quite the opposite in this sense that every step of the system can be adjusted and altered manually (Ciftcioglu and Bittermann, 2015). Fuzzy Neural Tree (FNT) model is also a neuro-fuzzy system

that combines Fuzzy Logic principles with Neural Network Systems. It is a very similar structure to NN, as it is also made up of nodes, inputs, weights and outputs. The main difference is that it is built neuron by neuron instead of layers of neurons, thus allowing much more flexibility and providing much more transparency (Ciftcioglu and Bittermann, 2015, Figure 2.11).

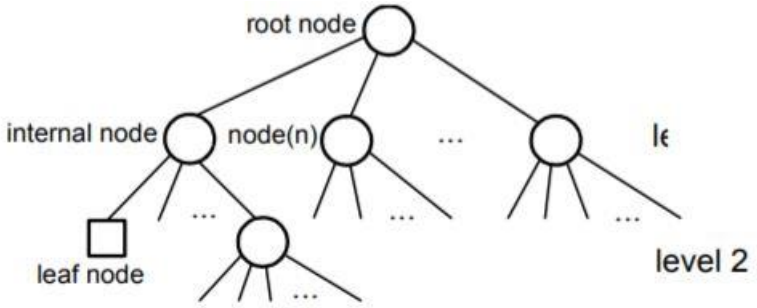


Figure 2.11: A Neural Tree Structure (Ciftcioglu and Bittermann, 2015, p.2).

In a study conducted by Ciftcioglu and Bittermann (2015) a novel type of FNT is researched. What is novel about the system is "fuzzy set of the membership function is formed by a likelihood function thereby processing probabilistic/possibilistic knowledge in the tree in terms of likelihood" (Ciftcioglu and Bittermann, 2015, p.1). Also, it presents a different approach towards FNT where it can work well with Soft Computing areas such as architectural design (Ciftcioglu and Bittermann, 2015).

Most of the objectives within the field of architectural design are intangible concepts thus making the evaluation process through quantitative elements difficult. However, verbal expressions can be easily defined through the use of the logical operators within FNT, allowing the designer to construct an evaluation system that can work well with architectural design problems as it can be seen in Figure 2.12 and Figure 2.13.

Through the use of the FNT structure presented by Ciftcioglu and Bittermann (2015), each node can represent a criterion to be passed along to the next node. As they have made their methodology accessible as a Grasshopper plugin, it can be integrated into the case study in this thesis. Each "AND" and "OR" operator within the Grasshopper definition functions in a similar way to the nodes in the FNT. They are connected to the model inputs with values between 0 and 1 according to how true or false they are and they are transferred to the upper branches depending on their truth value.

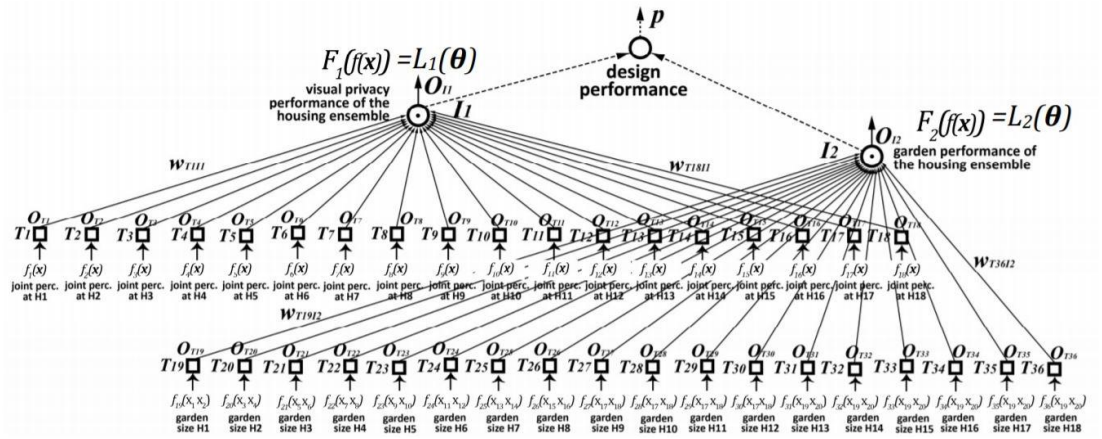


Figure 2.12: "Fuzzy neural tree model of the housing problem" (Ciftcioglu and Bittermann, 2015, p.7)

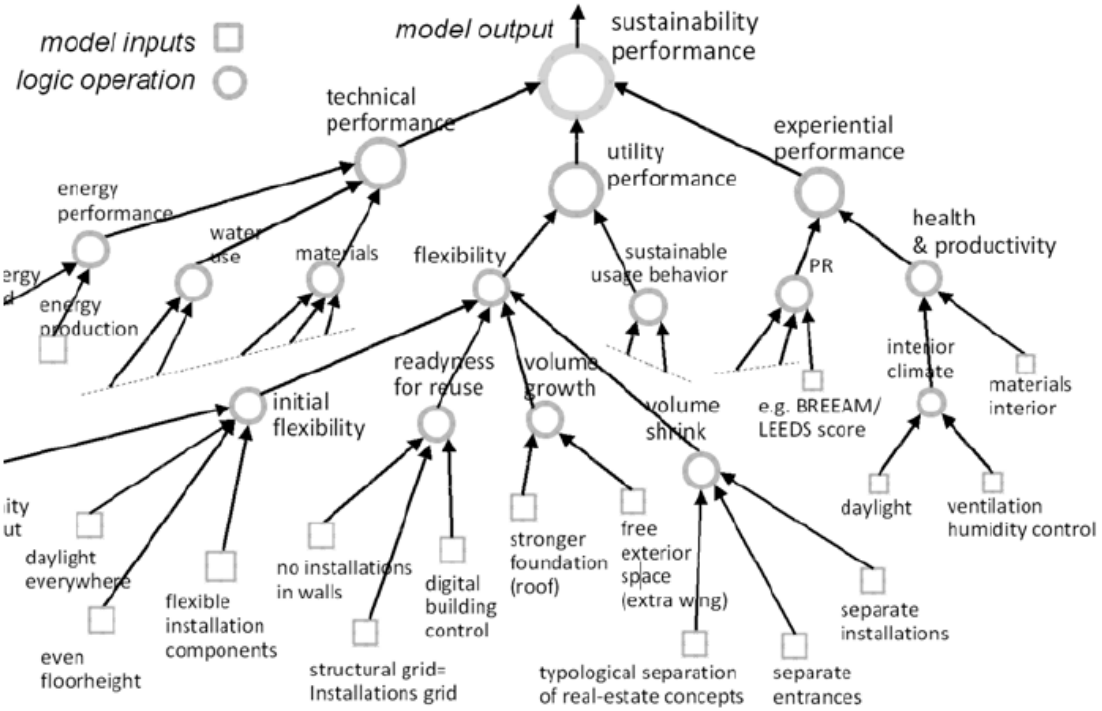


Figure 2.13: A fuzzy tree structure example (Bittermann and Sarıyıldız, 2010, p.9).

3. PREVIOUS DISASTER RELIEF DESIGN EXAMPLES

There are many examples designed or built for a post-disaster situation. In this chaper, selected examples will be analyzed and discussed in reference to the case study in this thesis. When analyzing these examples, the concepts selected in the first chapter will set the base, as they are determined through an overview on major problems and main concepts in disaster relief settlements. The requirements of a shelter or the aspects to look for when designing a post-disaster shelter have been listed as *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint* and *Computational Design Process.* Some of the selected examples from the literature have been examined and they are evaluated according to these aspects. Each one of these examples focus on satisfying a different aspect of the humanitarian design task and they manage to present various solutions to this particular design task.

One of the previous examples is named Mob-ARCH and it follows a methodological architectural design approach (Şener and Altun, 2009, Figure 3.1). It strives to underline the needs of the users and find solutions for the points that were lacking in the built examples. In that sense, MobARCH has a similar approach to this study as it also sets its design goals and evaluation criteria from the very beginning. It achieves the objectives related to detail design, reusability and small footprint, but it has limited potential in creating customization according to different users. The strong aspects of the study can be listed as *Upgrade Potential* and *Small Carbon Footprint*. It is upgradable because, the skeleton of the shelter is quite durable and can allow alterations in the envelope in time, expanding the period of service. It leaves a rather *Small Carbon Footprint* as the structure touches the ground lightly, elevated on four pedestals. So, when it is relocated, it leaves a minor effect on the site. On the contrary, lack of modularity causes the settlement to be weaker in presenting a customizable environment and results in a whole made up of repetitive units.

Another example named Ski Shelter utilizes uses disposable skis as the structural support material for a disaster relief tent (Figure 3.2). Even though the result is not very appropriate for long-term use and user alterations, reusing such an efficient and

strong material for a completely different function offers a new perspective. In addition, the indoor environment of the final structure is simulated through computer software in order to understand the indoor comfort within the tent (Salvalai et al., 2017). So, Ski Shelter presents a strong example focused on *Small Carbon Footprint* whereas it again fails in creating differentiation through *Modularity.*

Figure 3.1: 1:1 Prototype of Mob-ARCH (Şener and Altun, 2009, p.69).

Figure 3.2:1:1 Prototype of Ski Shelter (Salvalai, 2017, p.1114).

One of the pioneers of disaster relief housing is Shigeru Ban Architects and their project named Paper Log Houses is one of the first examples they designed in this particular context. It is a post-disaster shelter unit built after the Kobe earthquake in Japan and it is made up of quite basic materials such as paper tubes stuffed with sponge as insulation and beer crates as the base (Figure 3.3, Figure 3.4). So, the construction materials are reused and recyclable and the structure can easily be dismantled.

Figure 3.3: Paper Log Houses built after Kobe earthquake (Shigeru Ban Architects, 1995).

Figure 3.4: Paper Log Houses built after Kobe earthquake, interior (Shigeru Ban Architects, 1995).

The whole design is carried out in the way that ensures affordability and low-cost construction, resulting in a unit that costs below 2000 U.S. dollars (Shigeru Ban Architects, 1995). Therefore, it manages to satisfy the *Small Carbon Footprint* aspect of the requirements. Also, it includes a different kind of *Modularity* as it is made up of basic paper tube structures that come together to form the envelope of the structure. It has been constructed in several different ways to adjust the climate of the construction site and presents a very strong example amongst disaster relief design examples. Also, the basic materials that constitute the unit can make the *Construction without External Help* possible. However, all these strong aspects do not prevent the resulting settlement from becoming another repetitive pattern made up of same exact units. As mentioned

in the previous chapters, one of the biggest problems in the post-disaster temporary settlements is the lack of an effort to create a sense of ownership and differentiation for the inhabitants. Considering the listed examples, a manual process may not be adequate to satisfy all the requirements of a disaster relief shelter. These examples are designed, manufactured and assembled manually, possibly resulting in a process that can fall short under post-disaster conditions. For instance, the Ski Shelter is constructed within four working days in a real-life scenario (Salvalai et al., 2017) which may not be fast enough to respond to urgent sheltering needs of hundreds of displaced people. It could have been much more efficient if it could be designed, produced and built through an automated process. As post-disaster construction is a multi-layered problem with several contradicting parameters to satisfy, the aid of a computational tool can help the process to be much faster and optimized.

In one of the previous studies that adopts a computational approach, the requirements play an important role in defining the parameters that control the form.The parameters are not just classified as physical but also contextual and climatic ones in order to be able to further deepen the architectural characteristics of the outcomes (Daher et al., 2015, Figure 3.5). Especially the struggle to define the contextual parameters within the frame of the cultural traits of the displaced population is rarely found within disaster relief design examples All the building elements are shaped by these parameters and they come together to form a modular structure (Figure 3.6).

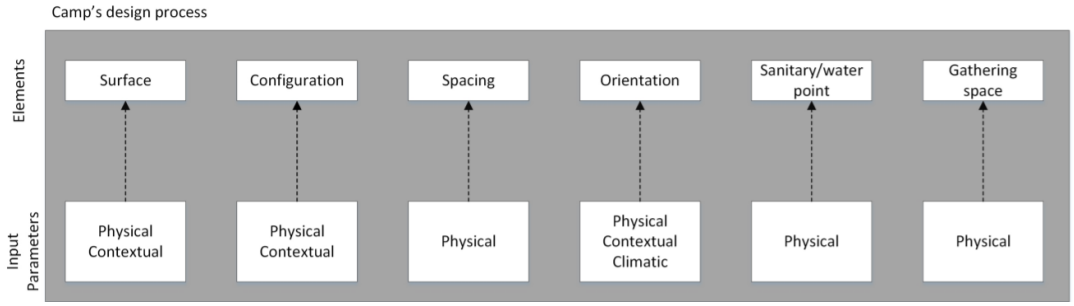


Figure 3.5: Parameter and the correlating entities – camp site (Daher et al., 2015, p.544).

The *Modularity* in this case is related to the surfaces that constitute one single unit, rather than the settlement itself. On the contrary, a modularity both within the building elements and the pieces of the settlement is expected to be achieved. Also, the study aims to create customized spaces according to different user types and achieve *Flexibility* that was lacking in the previous examples. Even though the parametric

model is constructed with a different methodology, this approach towards creating *Flexibility* through personalized units is similar to the one in this thesis. Also, their design is focused on designing each and every unit by changing the parameters whereas the design of a settlement pattern is more in focus in this thesis.

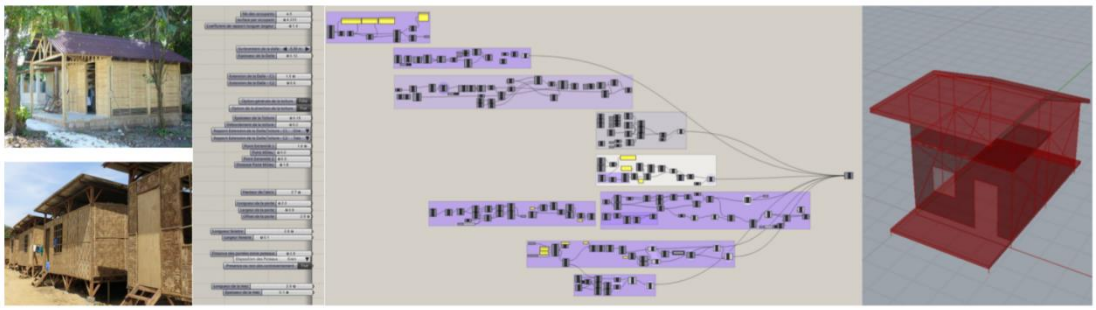


Figure 3.6: The design model and final products (Daher et al., 2015, p.546).

Another example that utilizes computational tools for the parametrization of units within a post-disaster settlement is based on the parametric modelling of a prefabricated temporary housing unit. The researcher determines the requirements of a temporary housing unit through the analysis of previous examples and then quantifies them to use as parameters for differentiation of the units in the next step (Rezoug, 2013). The study also aims to overcome the problem of repetition and the use of identical units in the post-disaster settlements. It achieves that by designing a model that can change its size, detailing, morphology and materiality according to different scenarios (Figure 3.7). This parametric approach allows the results to fullfill the *Modularity* and *Flexibility* aspects in a similar way to the previous study by Daher et. al (2015). Also, different options designed with the digital model are produced with *Digital Fabrication* tools, resulting in a more holistic approach (Figure 3.8). Although the struggle to create modular units that differentiate is similar to the one in this thesis, the methodologies differ. Due to its structural properties and the modular envelope, it can be upgraded in time.

Another research that uses parametric design as a tool for creating differentiation and customization amongst the post-disaster settlement, achieves this objective through the use of container units. The study is based on the works produced as the outcomes of a computational design studio that puts post-disaster shelter design in the centre of the question (Torus and Şener, 2015).

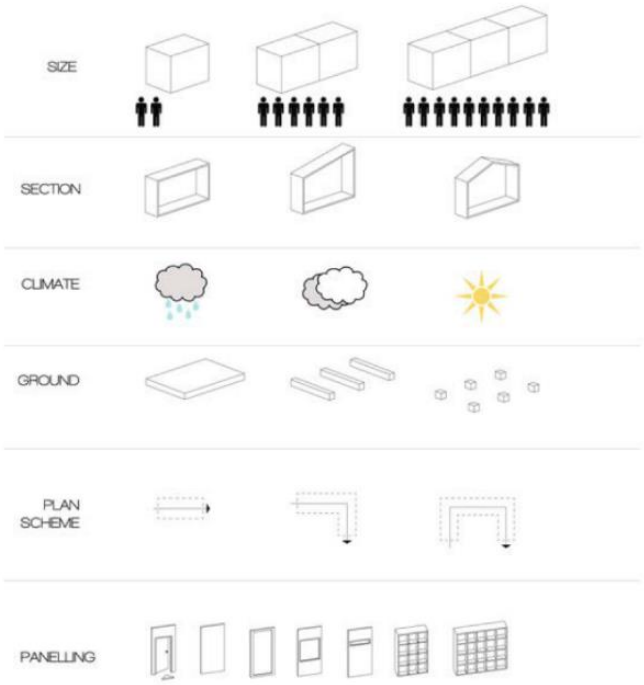


Figure 3.7: Parameters of the prefabricated units (Rezoug, 2013, p.32).

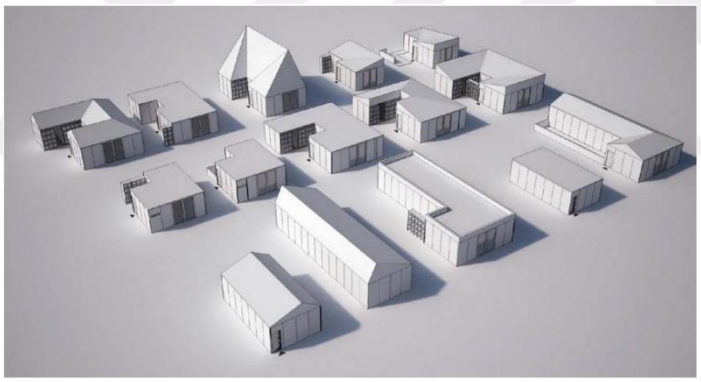


Figure 3.8: Different types of units produced through the parametric model (Rezoug, 2013, p.44).

Especially the design named CPoDs (Container Post-Disaster Shelters) which is made up of containers of different sizes is selected to be further developed (Figure 3.9). An interface gives the opportunity to change the parameters such as the number of users and users or the size of the settlement area and different arrangements are obtained through the use of generative algorithms (Şener and Torus, 2009, Figure 3.10). These parameters result in various configurations allowing the construction of a modular structure made up of containers. The *Modularity* in this case is achieved through the repetition of modules in the settlement scale, in a similar way to the one in this thesis. Also, *Flexibility* in this case is not in direct correlation with the units themselves, as containers are not personalized or parametrized by anything other than their sizes.

Their main objective is not creating customized spaces within the structure, but creating a settlement pattern that can adapt to different scenerio. Therefore, *Flexibility* in this example is also in the settlement scale, rather than the unit scale. Another strength of CPoDs is that it leaves a *Small Carbon Footprint* as it is using containers as the main construction element. This way, the whole structure is made up of reused materials as containers and the transportation of the containers to the construction site becomes quite easy. CPoDs are similar to this thesis in the way that it focuses on the settlement design rather than the unit itself, but again the methodologies are different.

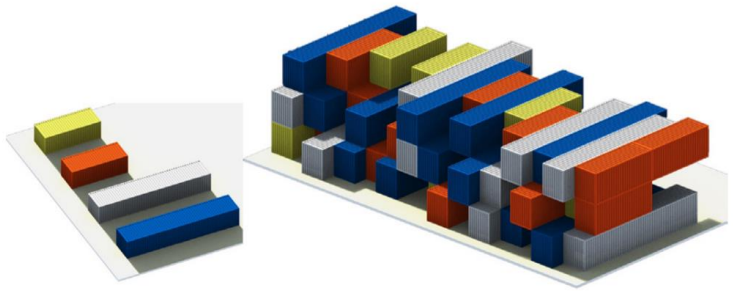


Figure 3.9: Types of containers of different sizes (Torus and Şener, 2015, p.279).

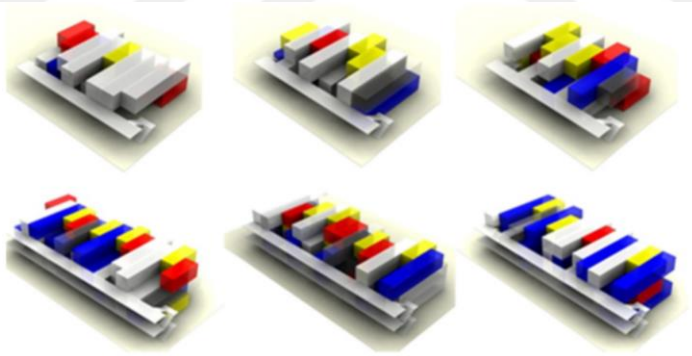


Figure 3.10: Different results designed with generative scripts (Şener and Torus, 2009, p.603).

Until the permanent housing is provided, modular construction for the temporary settlements can make a significant difference in terms of time and efficiency (Gunawardena et al., 2014). Automated production is an inseparable part of the modular construction and through the use of prefabricated modules, the settlements can be established in very short times. Especially the utilization of digital fabrication tools can serve as an important element in designing a holistic digital model which contains all the steps from the conceptual design to the construction.

One of the best examples demonstrating the efficient use of *Digital Fabrication* is the Instant House. It is focused on the use of a system that can translate the components of a digital model into a production manual houses (Sass and Botha, 2006, Figure 3.11, Figure 3.12).

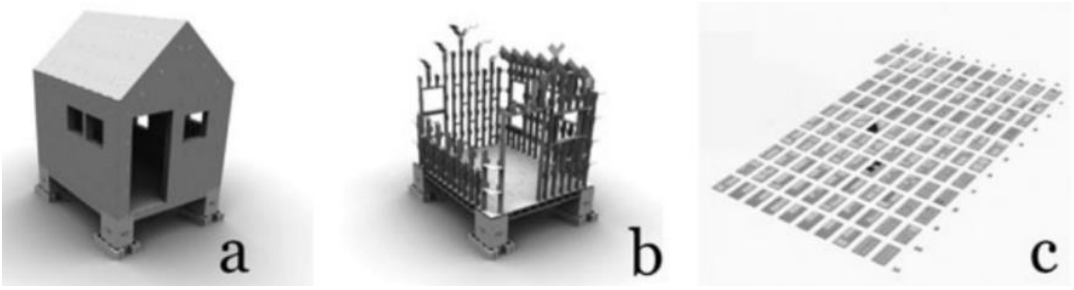


Figure 3.11: Initial model *(a)*, Construction simulation *(b)*, Sheets to be cut by CNC *(c)* (Sass and Botha, 2006, p.117).

Figure 3.12: Lightweight pieces, easy to carry and assemble (Sass and Botha, 2006, p.119).

It aims the fabrication of building elements on site through the use of digital tools and presents an option where the users can manufacture and build their own houses (Sass and Botha, 2006). The case of Instant House shows a great example of the holistic approach towards architectural design and fabrication. The pieces that constitute the structure are easy to carry and assemble, making it possible for the users to build it themselves. Therefore, the main strengths of this example can be listed as *Digital Fabrication and Construction without External Help*. The case study in this thesis has not yet been developed to the fabrication phase but the methodology of Instant House can serve as a solid base for the current study.

Shape grammars are the recursive application of certain rules on an initial shape and it is a term first introduced by Stiny (1980). The initial shape and the shape rules are the basic elements of shape grammars. The initial shape is the first shape introduced to the code, for the shape rules to be applied. Through this rule-based process, the initial shape grows into another form (Figure 3.13, Figure 3.14).

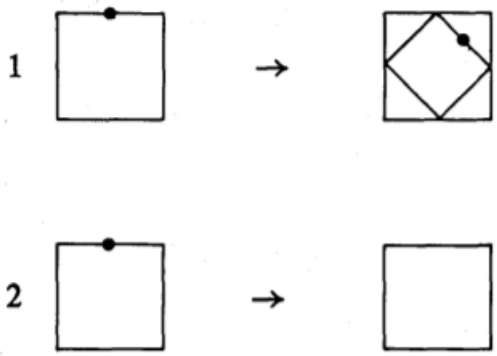


Figure 3.13: Two basic shape rules (Stiny, 1980, p.6).

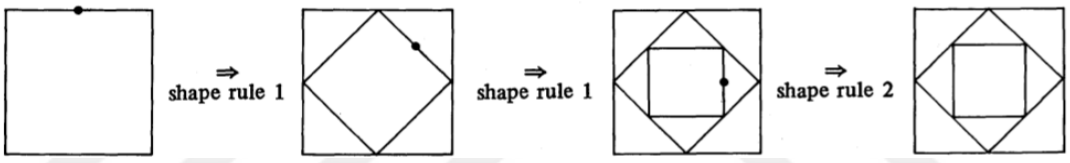


Figure 3.14: A shape generated with these rules (Stiny, 1980, p.6).

In one of the disaster relief designs that use a computational design process, Shape Grammars have been used to define a "Shelter Grammar" (Gonçalves, 2014, Figure 2.9). These recursive rules have been implemented as a decision-making tool in designing the plan schemes of shelters The building elements are all added one by one according to the defined relationships making it possible to have different plan layouts for a shelter settlement (Gonçalves, 2014). In this example, applying the shape grammars to the production of plan layouts for shelters seems to serve as a quick solution and an efficient decision making tool in the conceptual phase. Also, it is a useful methodology when the case is a modular structure. As a result, the study achieves an effective solution to *Modularity* in construction, putting the design of a unit in the center of question. The unit can differentiate in various scenerio, thus embedding the *Flexibility* aspect in the digital model. As it is still in progress, its integration with Digital Fabrication is still not completed. The recursive application of certain rules and constructing the plan layout accordingly is very similar to the case

study in this thesis. However, a rule-based growth can be taken further into the next step as presented in the study by Choucoulas (2003) in the second chapter. Evaluating the form each time the rule is applied and altering the rules according to this evaluation can result in much more interesting results.

Figure 3.15: A part of the plan layout generation process (Gonçavles, 2014, p.334).

All these selected examples present a different point of view to disaster relief design. They work with this task in different scales such as the detailing and design of a single unit or generating a settlement pattern. However, it has been possible to analyze and understand each of them through the aspects determined in the first section. These aspects are *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint and Computational Design Process* and they summarize the points to look for when designing a post-disaster shelter. The examples above are mapped on a table, to underline which of these aspects they accommodate (Table 3.1). Each one of these examples focus on satisfying a different aspect of the humanitarian design task and they manage to present various solutions.

Table 3.1: Previous examples in post-disaster context and the aspects they focus on.

	Modularity	Flexibility	Upgrade Potential	Digital Fabrication	Construc-tion without external help	Small Carbon Footprint	Computa-tional Design Process
MOBARCH (Şener and Altun, 2009)			x			x	
Ski Shelter (Salvalai, 2017)			x			x	
Paper Log Houses (Shigeru Ban Architects, 1995)	x				X	x	
Shelter Design (Daher et al., 2015)	x	x		x			x
Fast, Cheap & Adaptable (Rezoug, 2013)	x	x	x	x			x
CPoDs (Torus and Şener, 2015)	x	x	x			x	x
Instant House (Sass and Botha, 2006)	x			x	X		x
Shelter Grammar (Gonçavles, 2014)	x	x					x

When this table is analyzed, it can be seen that traditional design processes result in better designs in terms of achieveing *Small Carbon Footprint.* The reason for that can be the tendency to focus on the resultant design rather than the design process itself, leaving more time for the construction and detailing part. Most often researchers who design manually focus on using recycled or reused materials and they try to integrate the potential to relocate into their designs. On the other hand, the designs produced through the use of computational design processes provide better results in *Modularity* and *Flexibility* most times since parametrization and modularization are much more integrated with computational tools. However, automating the system for faster results, experimenting with forms and designing the process itself overshadows the construction phase. If these two approaches can unite their strengths, much better and holistic designs in the context of post-disaster construction can be obtained.

4. CASE STUDY: DESIGNING A POST-DISASTER SETTLEMENT

This thesis is focused on designing a temporary living space that can respond to the needs of different post-disaster scenarios and form a modular system through differentiation of units. The main aspects to look for in a shelter design have been chosen as *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint and Computational Design Process* in the previous chapters. These aspects also set the basic idea behind all the rules and design decisions for the case study in the following sections. Towards this aim, an algorithm that defines the rules of the growth pattern is constructed and a definition in Grasshopper is designed to alter this algorithm as the pattern grows (Figure 4.1).

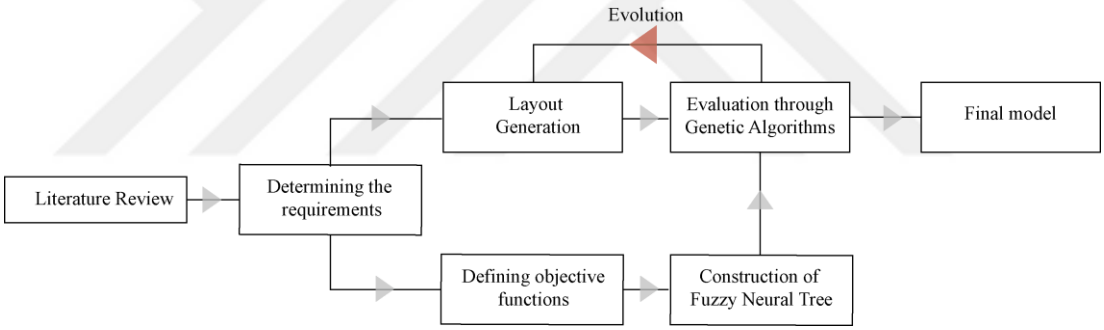


Figure 4.1: Steps of the design.

These alterations are applied by the Multi-Objective Genetic Algorithms (MOGAs) in order to improve the outcomes in comparison to the evaluation criteria. The objective function that will evaluate the configurations is constructed using Fuzzy Neural Tree (FNT). Therefore, the case study in this thesis focuses on the design of the growth algorithm, the construction of the objective function node by node on the FNT and the evaluation of the algorithm according to these objective functions. One of the biggest problems in the previous disaster relief shelter/housing examples is the composition made up of identical units as discussed in the previous chapters. Therefore, the flexibility of the modules carries a crucial role in supporting a sense of ownership of the users. One of the ways to achieve that is enhancing the transformable quality of the modules in order to create an upgrade potential in time. The ability of the settlement

to transform from a temporary to a transitional or even a progressive shelter can be achieved through the modifiable modules. Its potential to grow in size can help it become more transformable and help it accommodate more people if necessary. As differentiated units provide more customized spaces for every family and open areas such as courtyards can give users the room to modify their external environment, they can be the key aspects in providing a higher quality environment.

4.1 Initial Assumptions and Modularity

As mentioned earier, *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint* and *Computational Design Process* have been chosen as the aspects to look for in a shelter design. These aspects help defining all the steps from the design process to construction phase. As a start, the main aspects to satisfy are chosen as *Modularity* and *Flexibility.* So, creating a shelter made up of repeating pieces and with differentiating spaces for each family, is the first step. As it is chosen to be a modular structure, a set of rules that define the growth algorithm has to be decided and listed clearly. This way, the algorithm can also be constructed in the digital environment. Through the application of the rules and definitions, a living space grows piece by piece, forming a modular pattern as a result. The pieces forming the pattern are made up of 3*3 m cubes as it is a standard size to define a meaningful space. Cubes are combined in different numbers to form the units with various functions and these units are combined to form the modules. Nine cubes form a basic module accommodating two families and three different units with three different functions are defined within this module (Figure 4.2, Figure 4.3):

- Unit A: Shared wet space (1 cube / 3*3=9 m²): A wet space used by two families for hygienic purposes.
- Unit B: Living space (2 cubes / 3*6=18 m²): The common area where families use for daily activities. It also includes space for cooking.
- Unit C: Personal space (1 cube / 3*3=9 m²): It is the space where members of the family can sleep or store their belongings. Every family has two personal space cubes.

The basic rules that constitute the algorithm are:

- All the cubes connect to each other from the centre of their edges. This way the construction phase is simplified and openings between different units do not present any problems.
- A wet space is shared by two living spaces. Therefore two units of B connects to A.
- A living space has a maximum two personal spaces, so every B unit can accommodate two C units at most.

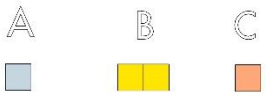


Figure 4.2: Different types of units made up of cubes.

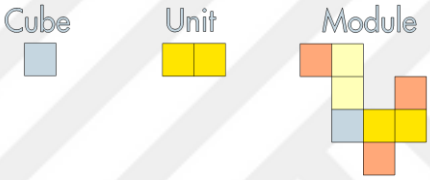


Figure 4.3: Concepts of cube, unit and module.

In order to test and solidify the algorithm, the combination possibilities in each step are listed manually. In the first step, a living space is connected to a wet space, which can also be named as the sum of A and B units: A+B (Figure 4.4).

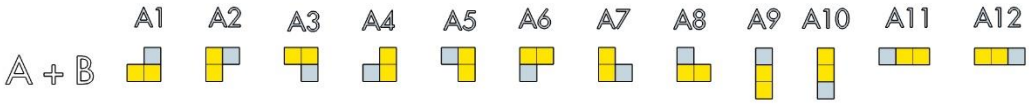


Figure 4.4: 12 possible outcomes of the combination of A and B units.

Firstly, a unit of wet space sets the basis for the growth pattern as it will be shared by two families. In each step, another cube is added according to the rules. The units in a module are differentiated in order to enhance the repetition problem observed in the previous examples. Secondly, a second living space is connected to the wet space unit. Even without moving further into different units, the number of outcomes reaches large numbers, thus proving the suitability of the algorithm for the presented design problem and presenting more options for Genetic Algorithms to test. In order to be able to exemplify the variety of options, a table that intersects the geometry from the previous step and the binding logic of A+B has been shown (Figure 4.5). On the third

step, the sample on the right upper corner from Figure 4.5 is chosen and the personal spaces are added to it (Figure 4.6). These figures demonstrate the rich variety of options created with very simple rules and manually. In the next phase, these geometries are constructed in Rhino 3D environment with the aid of Grasshopper.

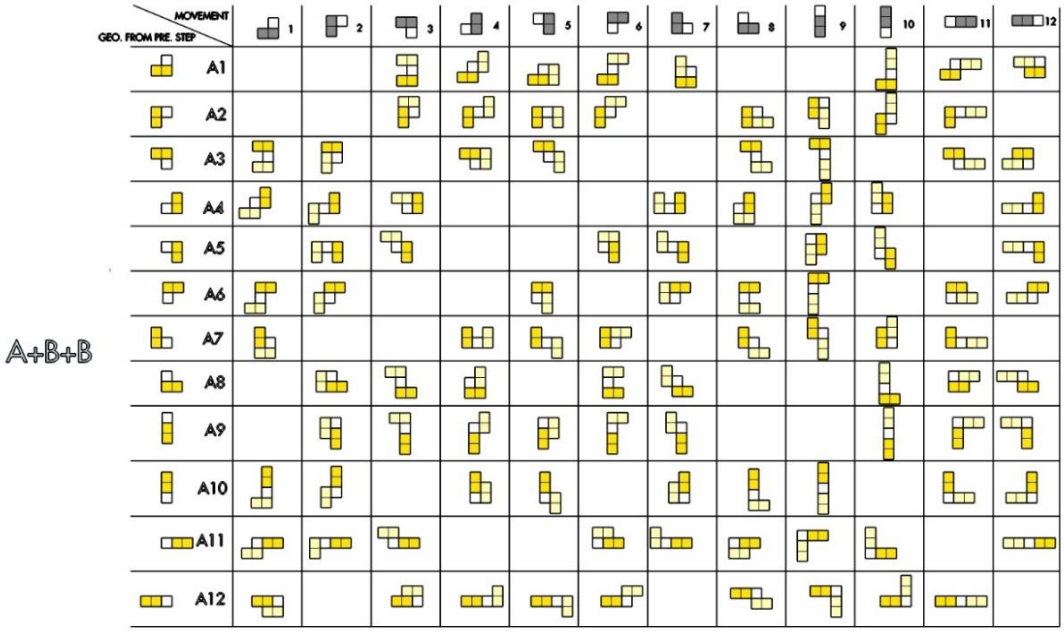


Figure 4.5: Possible outcomes of the combination of a wet space with two living spaces.

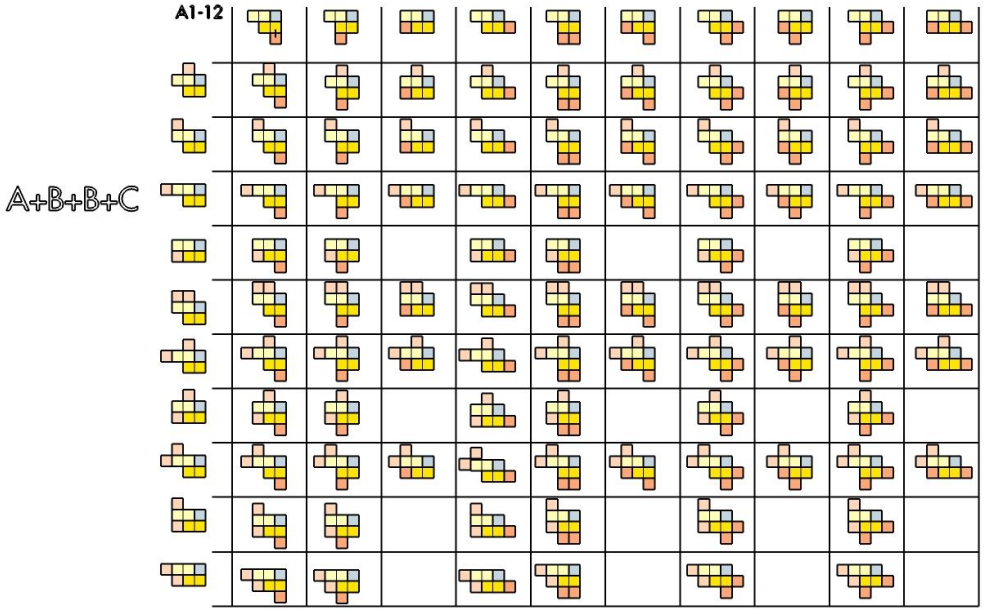


Figure 4.6: The possible outcomes of the combination of a selected A+B+B and C units.

4.2 Layout Generation

The rules formed in the previous section are utilized as the basis of the operations in the layout generation phase. Initially, the rules stated for the additive architectural shaping were going to be used for the generation of all the possible 2D layouts. Then the layouts would be evaluated one by one and GAs would choose the best options. However, it is much more efficient for the GAs to decide the growth pattern whilst testing it at the same time.

For the generation of the first module, a cube representing unit A-the wet space is placed in Grasshopper as the initial object for the geometry to grow from. With the move component, each new cube is added to the previous one; however, the transformation in this situation takes place with the aid of C# codes within the definition (Appendix A). The code defines the vector that the movement is based on and the four possible empty spots around the cube are defined as four different vectors for the move operation to take place (Figure 4.7).

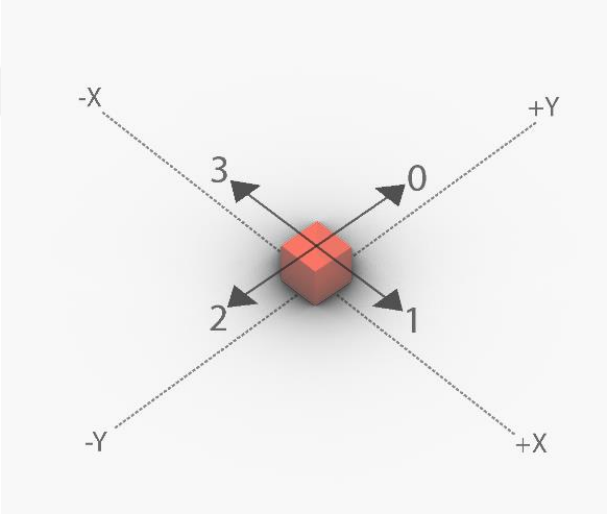


Figure 4.7: Four vector directions for the addition of the new unit.

The number slider with four integers is used in order to symbolize these vectors and all the number sliders are connected to the multi-objective genetic algorithm component as parameters. Therefore, genetic algorithms can determine the growth direction of the pattern in the process of evaluating the shape. After the second cube is attached to the first one, the third one attaches to the second one in order to form the A+B units. However, this time it is known that there are only three available spots for the new cube to attach. Therefore, in order to cancel out the collisions the movement

direction is rotated according to the previous vector (Figure 4.8). The new direction only considers three possible directions, decreasing the number of options for genetic algorithms to deal with.

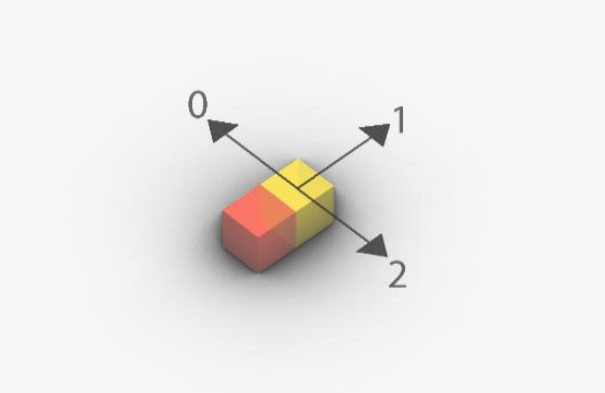


Figure 4.8: The rotated vectors to avoid collisions.

If the new cube is again representing a piece of unit B, it is again attached to the initial cube which is unit A. As unit A accommodates two B units, it is crucial to avoid placing them in the same direction. In order to achieve that C# code places the second unit B according to the position of the first unit B (Appendix B). If the second number slider is set to the same number, it is automatically changed to another direction randomly. Therefore, the system already behaves in the direction to avoid collision. As a result of these repetitive operations, A, B and C units come together to form a module made up of nine cubes (Figure 4.9). The Grasshopper definition that is used for the construction of one module can be seen in Figure 4.10.

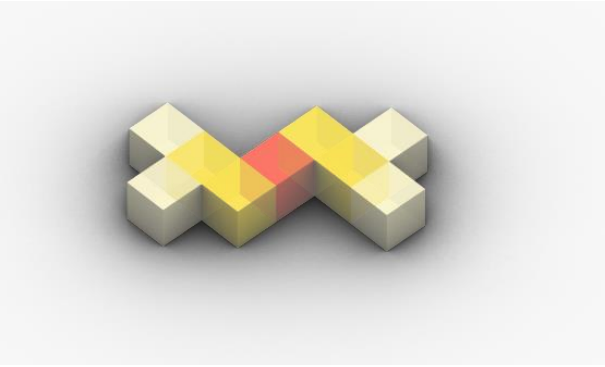


Figure 4.9: A module made up of nine cubes.

In the next step, a new module attaches to the completed one. Firstly, the first module is taken into a bounding box to determine its borders. The bottom surface of this bounding box is extracted and its edges are divided into twenty possible points for the

first cube of the new module to attach. Therefore, this point that the new module will start from is also a parameter for MOGAs to adjust alongside the proximity of the points from the first module. The first cube to attach to one of these points from its central point again represents the wet space-unit A and sets the base for the other units to attach (Figure 4.11). With the same method described above, another module grows around the first one, within the control of MOGAs (Figure 4.12). To use the area effectively, four modules are placed around the first one, creating a “neighborhood node” (Figure 4.13). This node can later be repeated multiple times to create a settlement pattern. The Grasshopper definition controlling the additional module attachments around the first one is presented in Figure 4.14 and the definition for the whole neighborhood node generation can be seen in Figure 4.15.

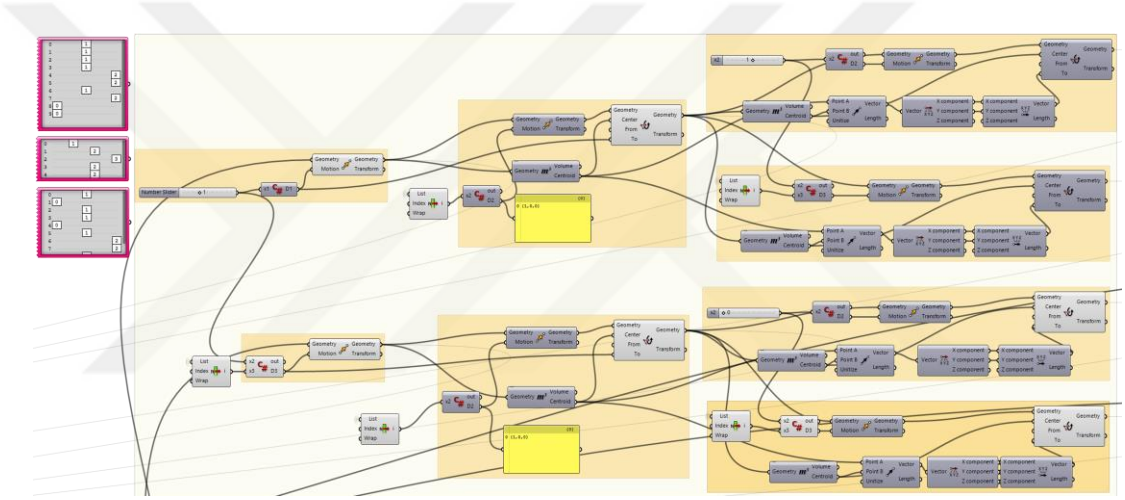


Figure 4.10: Grasshopper definition of a single module.

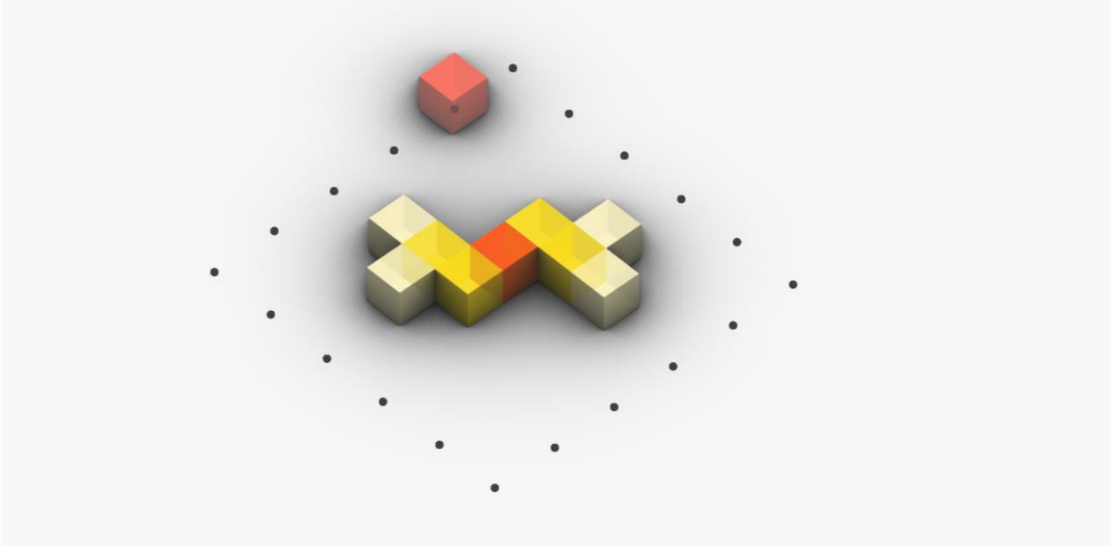


Figure 4.11: The first cube of the second module attaches to one of the points around the first one.

Figure 4.12: The second module then grows around the attached cube.

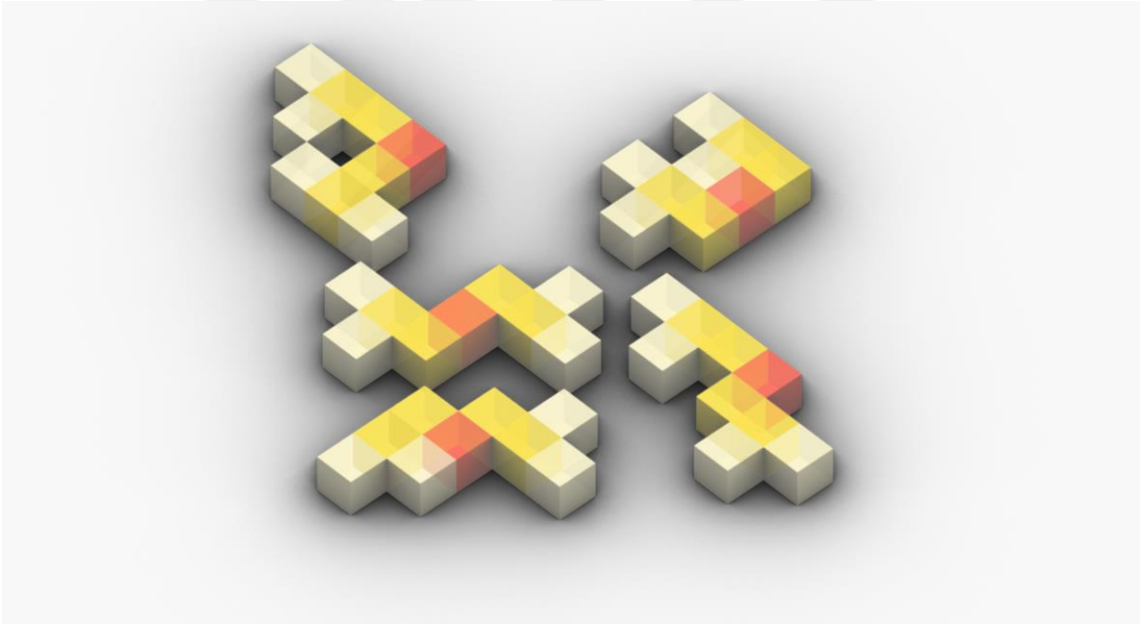


Figure 4.13: A neighbourhood node with five modules.

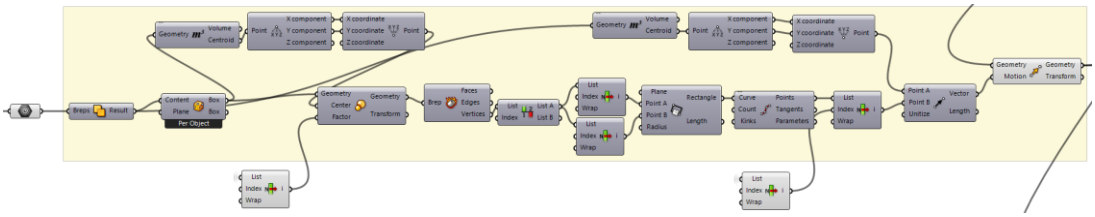


Figure 4.14: Grasshopper Definition that determines additional module attachment.

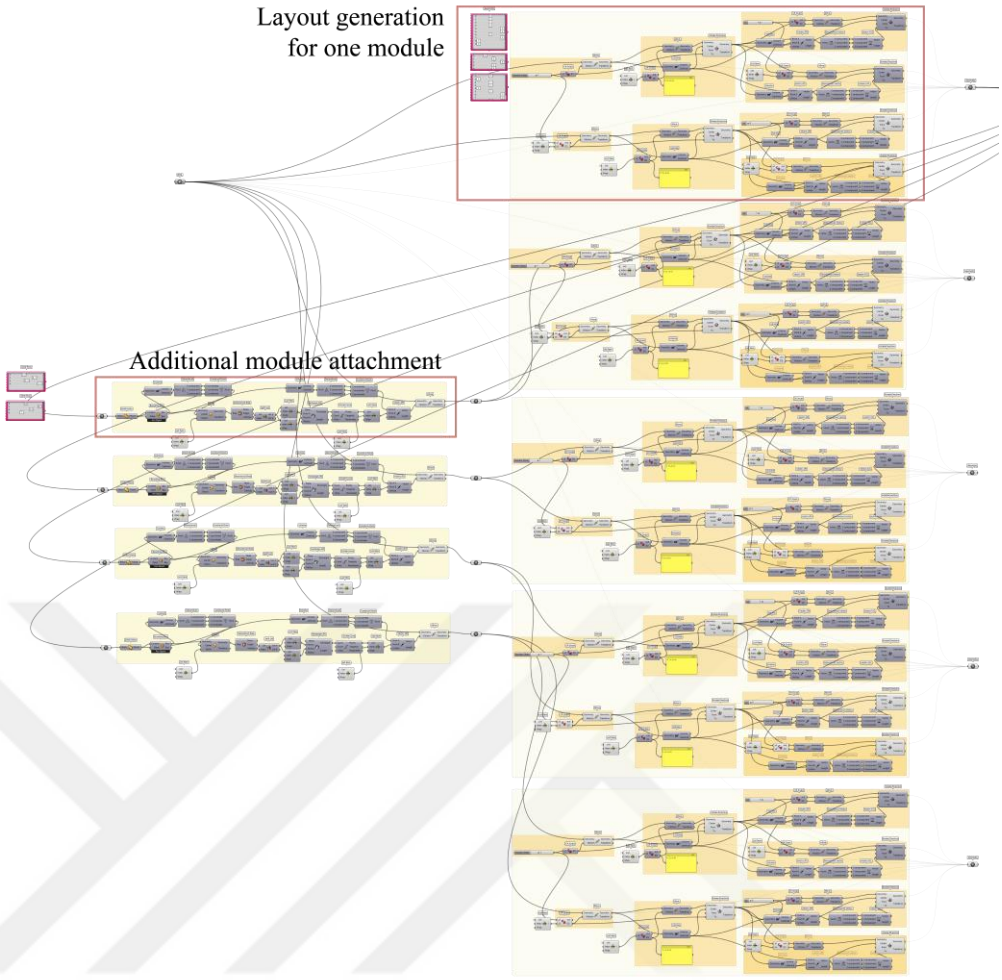


Figure 4.15: Grasshopper definition of the neighbourhood node.

4.3 Objective Functions and Evaluation

Since the disaster relief living space is expected to satisfy various competing objectives, MOGAs are considered to be the most suitable option for the evaluation phase. MOGAs are often used for solving architectural design problems as they work for the optimization of contradicting objectives. There are various methods for the construction of the objective functions for MOGAs, but in this study Fuzzy Neural Tree (FNT) is chosen as the main method. It is a structure made up of neurons with AND and OR operators (Ciftcioglu and Bittermann, 2015). Most of the objectives within the field of architectural design are intangible concepts thus making the evaluation process through quantitative elements difficult. However, verbal expressions can be easily defined through the use of the logical operators within the fuzzy neural tree, allowing the designer to construct an evaluation system that can work well with architectural design problems. Each operator within the Grasshopper

definition functions in a similar way to the neurons in the neural networks. However, an FNT is constructed neuron by neuron with these operators, unlike the growth by layers in neural networks. The neurons are connected to the model inputs with values between 0 and 1 according to how true or false they are. Then each neuron again produces an output between 0 and 1 to be transferred to the following neuron. Eventually, this interconnected system forms the objective function with an output value that MOGAs strive to achieve by altering the parameters (Figure 4.16).

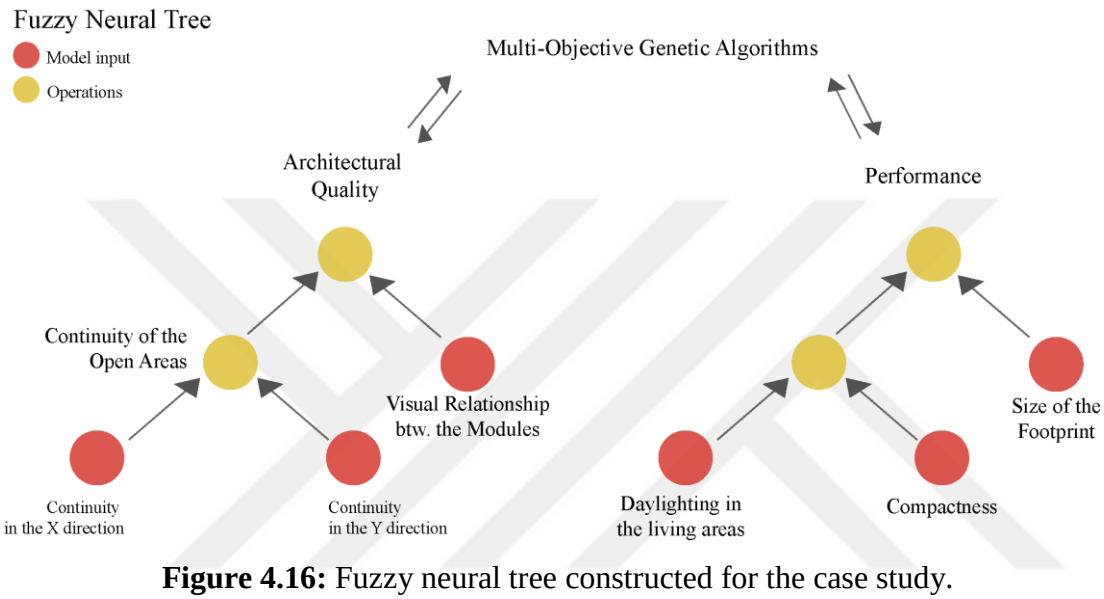


Figure 4.16: Fuzzy neural tree constructed for the case study.

One of the main challenges is determining the goals that will produce the inputs for the neurons in the FNT. It can be difficult to choose one single correct definition for each goal but it is possible to define them through the analysis of the previous examples with similar functions and also through an intuitive understanding of architecture. In the previous sections *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint* and *Computational Design Process* have been chosen as the aspects to look for in disaster relief shelters. The algorithm defining the growth of the shelter system has already been constructed considering some of these aspects. However, the rest has to be interpreted and defined in order to be integrated in the evaluation phase. Even though the evaluation criteria within FNT is not selected in direct reference to these characteristics, it takes inspiration from them as they are the goals for the final design to reach. So, the criteria constituting the FNT is selected and constructed through an intutive understanding of architecture, through the interpretation of some of these aspects and the decisions

given by the researcher. They are grouped into two main titles as performance and architectural quality and they are explained in detail in the following sections.

4.3.1 Objective functions related to performance

Even though it is a temporary settlement, performance of the indoor environment can affect the user comfort dramatically. In this sense, daylighting in living spaces, compactness and size of the footprint are chosen as the inputs of the performance score. Daylighting is only calculated in the living spaces through the number of the faces they have towards outside. Compactness is calculated through the vertical surface areas and size of the footprint is calculated considering the spread of the total mass. Then, their results are connected to an AND operator as it is crucial to optimize all of them.

4.3.1.1 Daylighting in living areas

Daylighting conditions are only calculated taking the living spaces into consideration. Firstly, all the living spaces are selected and their exterior surfaces are detected. Only the centroid of the vertical surfaces are determined and those centroids are moved to the bottom surface. These points represent the surfaces surrounding the living spaces. Then, the outline of the outdoor areas on the bottom surface is selected (Figure 4.17).

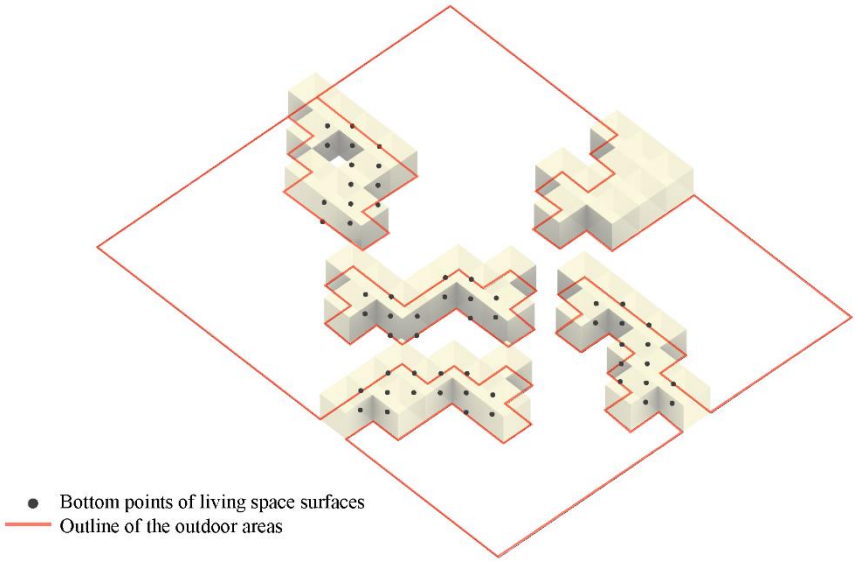


Figure 4.17: The number of the bottom points of living space surfaces located on the outline of the outdoor areas.

The number of points that are located on this border is considered to be the number of surfaces that living spaces can receive daylight. When the possible configurations are tested, it has been seen that the maximum number of exterior surfaces that living spaces can receive light within a module is six. Therefore, living spaces can have a maximum of thirty surfaces towards outside. With this in mind, the number in the current state takes a value between 0 (*False*) and 1 (*True*) where 1 is the equivalent of thirty points. The Grasshopper definition showing the daylight crtierion assessment can be seen in Figure 4.18.

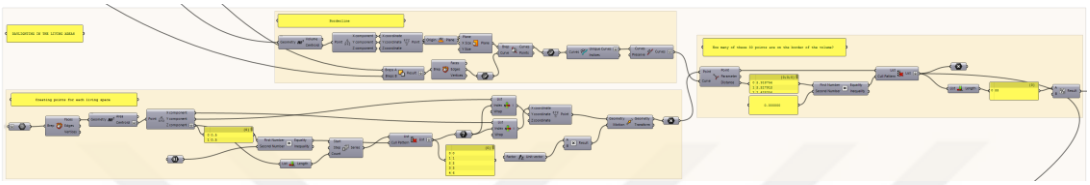


Figure 4.18: Grasshopper definition of the daylighting in the living spaces.

4.3.1.2 Compactness

The buildings tend to have lower thermal performance as their exterior envelope grows. As a volume becomes more compact, its energy losses through the surface drops. Therefore, in order to be able to create a compact volume as much as possible, the area of the modules' vertical exterior envelope is calculated (Figure 4.19, Figure 4.20).

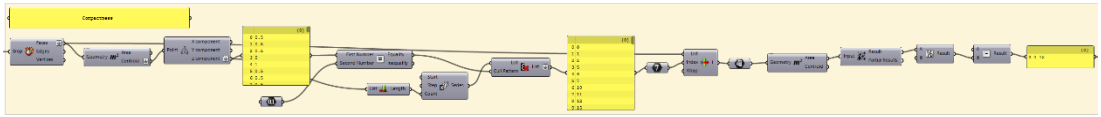


Figure 4.19: Grasshopper definition of the compactness criterion.

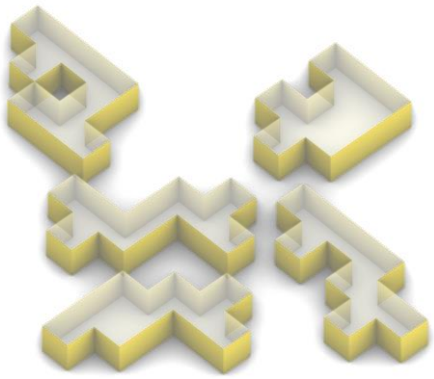


Figure 4.20: Exterior wall surfaces for the measure of compactness.

4.3.1.3 Footprint of the structure

As transitional shelters are set up for only a limited amount of time, they are expected to affect the area that they are set up as little as possible. Also, it is more preferable for them to take up a smaller space in terms of surface area in order to accommodate more people in a smaller area. With these in mind, the footprint of a post-disaster settlement is expected to be as small as possible. Therefore, the surface area of the bounding box of the neighbourhood node is aimed to have the smallest value possible. The smallest footprint the structure can have is calculated as fourty-five sqm and it is divided by the surface area of the current configuration (Figure 4.21). The number is a value between 0 (*False*) and 1 (*True*) and it serves as the input of the neuron.

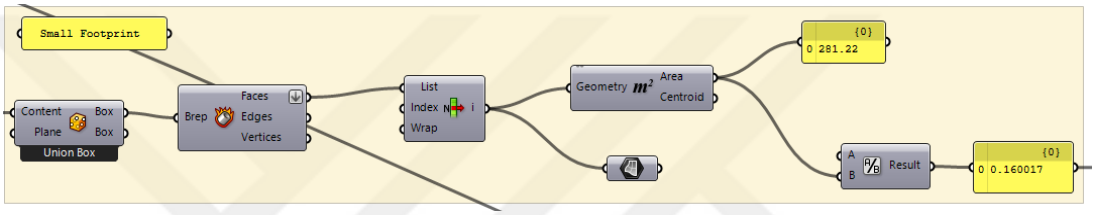


Figure 4.21: Grasshopper definition of the footprint of the structure criterion.

4.3.2 Objective functions related to architectural quality

Different from the goals related to performance, the goals related to architectural quality tend to be more subjective and open to interpretation. In this study, the goals are concentrated on the most basic needs a post-disaster settlement can have. They are originated from the analysis of the previous examples, where lack of flexibility and differentiation have been the major problems.

In this sense, continuity of the open areas and visual relationship between modules leaves behind are chosen as the major points to evaluate the architectural quality of a post-disaster living space.

4.3.2.1 Continuity of the open areas

In order to form a sense of community, four more modules are placed around the first one, creating a “neighborhood node”. As new modules are added to the first one, spaces in between are formed. They represent the outdoor areas within the settlement and they are vested with a crucial role in creating a higher quality atmosphere for its residents. The relationship between different courtyards tells quite a lot about the open spaces. It is much more useful and accessible for them to be continuous and spacious

in dimensions, than being divided and stuck between volumes. In order to evaluate the continuity of these areas, the open areas within one neighbourhood node are taken into consideration.

Firstly, the modules are surrounded by a bounding box where its surface is determined for the next step. This surface is divided into equal pieces with lines in the X and Y directions (Figure 4.22).

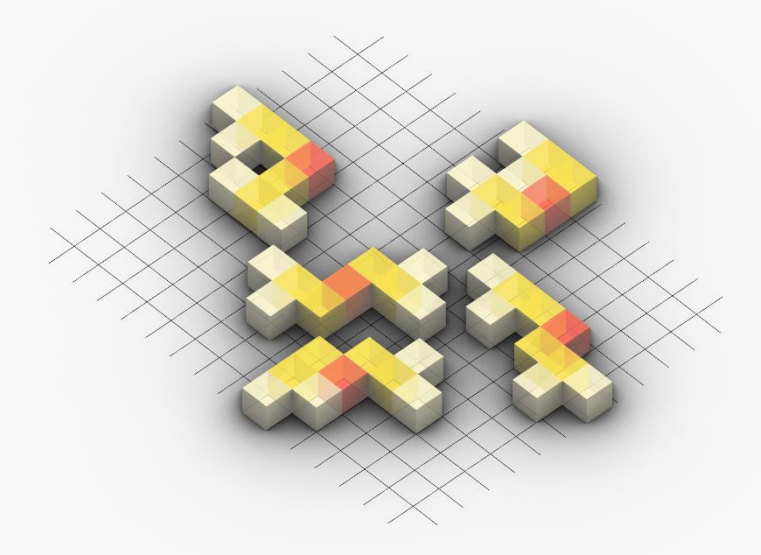


Figure 4.22: Lines in the X and Y directions to test the continuity of open areas.

Then, the modules are subtracted from the bounding box in order to obtain the open spaces. The volume representing the outdoor areas in between the modules is intersected with the lines created earlier (Figure 4.23).

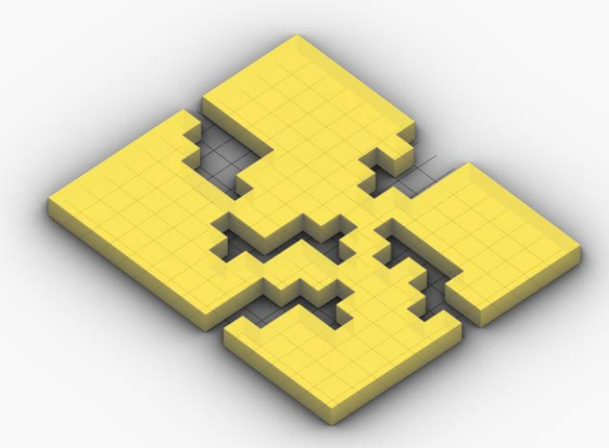


Figure 4.23: The volume representing the outdoor areas is intersected with the test lines in both directions.

The lengths of the lines within the surface represent the continuity of the outdoor areas. The longest lines in the X and Y directions are chosen to assess the continuity of the open spaces. In order to determine their correspondent value of the continuity within 0-1 range, the largest lengths are divided by the dimensions of the surface area in the respective directions. The values in the X and Y directions are then utilized to generate the model input for the AND operator in the fuzzy neural tree. The output of the operator gives a truth value describing the continuity of the outdoor areas in both directions (Figure 4.24).

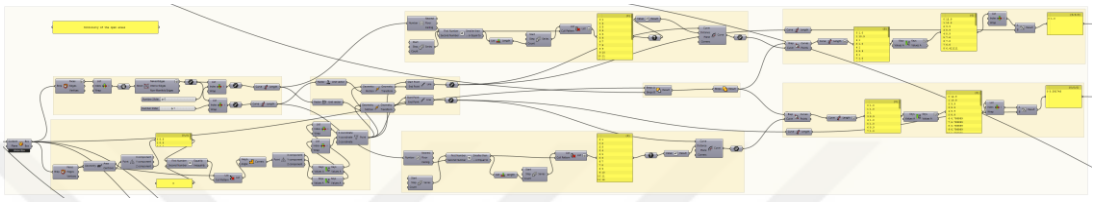


Figure 4.24: Grasshopper definition of the continuity test.

4.3.2.2 Visual relationship between modules

Visual relationships between different modules are conducted by only taking living spaces into consideration as they are the common area for the family members to share and spend the most time. The proximity of the living spaces to the neighbouring modules give clues about the privacy of the modules and the perspectives each living space have. Being too close to the neighbouring module can create unpleasant spaces both within and around the structure. If the spaces in between the modules are too small, they can create unpractical narrow alleys that even people cannot pass through. Therefore, it is important to assess the visual relationships between living spaces and to check the distances in between the modules. In order to achieve that, the points that were detected for the daylighting evaluation and that represent the exterior surfaces of the living spaces are chosen. These points are moved in four different directions to determine which side of the surface is looking outside. The direction that the point does not coincide with the total volume is chosen as the direction to test the visual relationship for the point in question. Lines representing the visual rays are sent from the points towards the detected directions. The points that visual rays hit the closest neighbouring volume are determined and their distance from the starting points of the rays are measured. The shortest pieces of each ray are sorted and their lengths are used for the generation of the model input (Figure 4.25). The minimum distance between

two modules thus the smallest lengths of the rays are assessed to determine whether they are bigger than 1,5 metres or not. All the values smaller than 1,5 metres turn a boolean into false, causing the configuration to be disqualified from evaluation and serving as a constraint for the MOGAs.

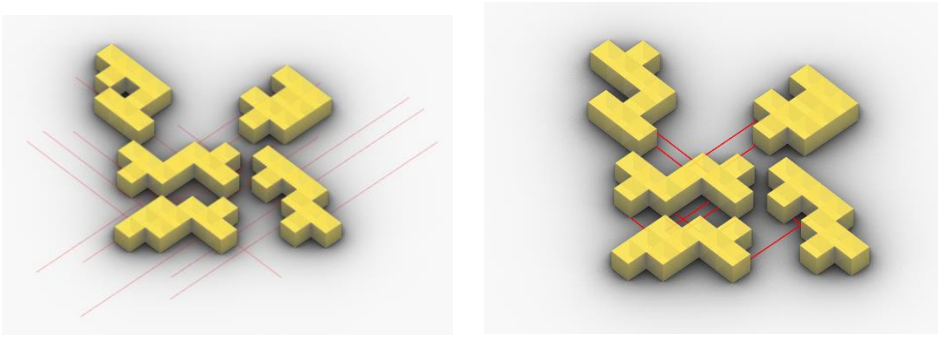


Figure 4.25: Visual rays sent to test the neighbouring module proximity *(left)*, Shortest distances between the modules *(right)*.

Then all the smallest distances are added up together in order to evaluate their value against the smallest value possible. The smallest total value possible, therefore the number that makes the value 0 (*False*) is calculated through the multiplication of the number of rays with the smallest possible distance of 1,5 m. Preferably, the difference between the smallest total value of distances and the total length of distances in the current configuration is expected to be as high as possible. Therefore, these two values are subtracted from each other and the result is translated into a value between 0 and 1 for the visual relationship input of the neuron.

4.3.3 Constraints

MOGAs can be restricted by various constraints that are represented in the type of a boolean. It works towards keeping the connected boolean value at *True* at all times and the configurations making the boolean value *False* are not included in the evaluation.

Firstly, as explained earlier, one of the constraints used in the configuration is the minimum distance between neighbouring modules. The minimum span between two modules cannot be smaller than 1,5 meters. Any value below that number gives out the *False* output from the connected boolean.

Secondly, one of the main problems throughout the growth of the module unit by the unit is the collisions between the cubes, and constraints can be quite useful in

preventing that. In order to express it in the form of a Boolean, collision between each cube and between the modules are checked with the collision component (Figure 4.26). Its result has to be kept *True* (no collision) at all times and it serves as a constraint for the genetic algorithms. However, in order to give more space to different options and provide some flexibility within the search space, collision up to 10% of the total volume has been allowed. Therefore, even if small parts of the cubes overlap each other, the configuration in question is taken into evaluation (Figure 4.27).

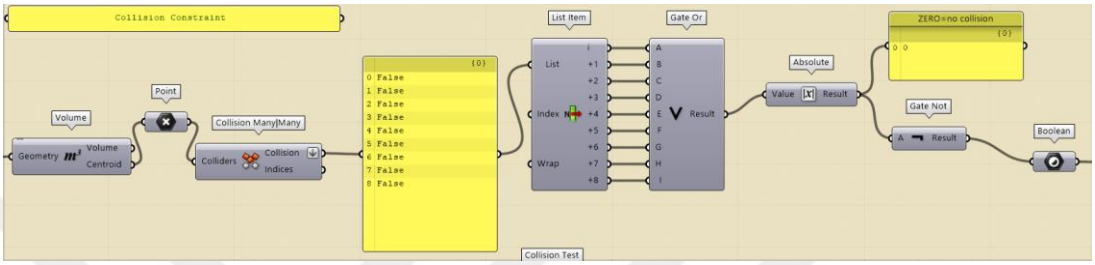
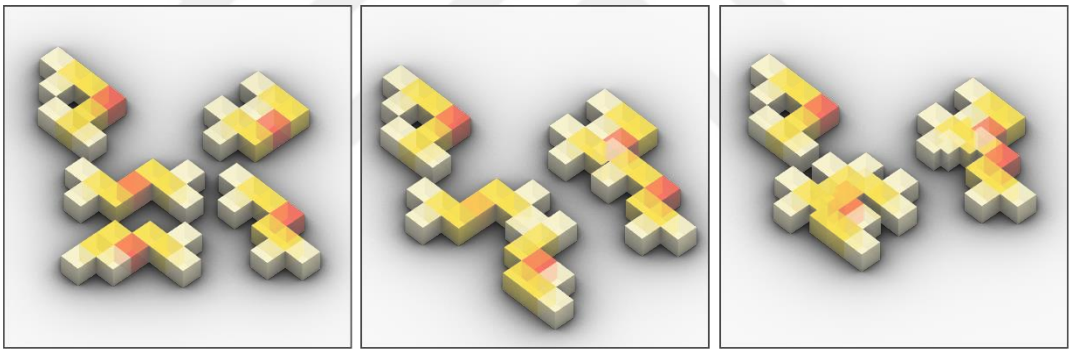


Figure 4.26: Grasshopper definition of the collision check for the cubes within a module.



True *True* *False*

Figure 4.27: Truth values of different configurations according to collision check.

4.4 Selection and Evaluation

For the evaluation, Octopus plugin of Grasshopper is used for the multi-optimization process. Octopus component controls the growth generation and then assess the configurations with the evaluation criteria in the Fuzzy Neural Tree. It scores the current configuration through truth values generated from FNT and it is compelled to keep the constraint value at *True* whilst doing that (Figure 4.28, Figure 4.29). Multi-Objective Genetic Algorithms (MOGAs) continued producing new offspring representing varying configurations until the sixtieth generation. It was stopped at

sixtieth generation as the system stopped find any new solutions on Pareto-optimal front. Fourty-eight genes and two objective functions are introduces to MOGAs.

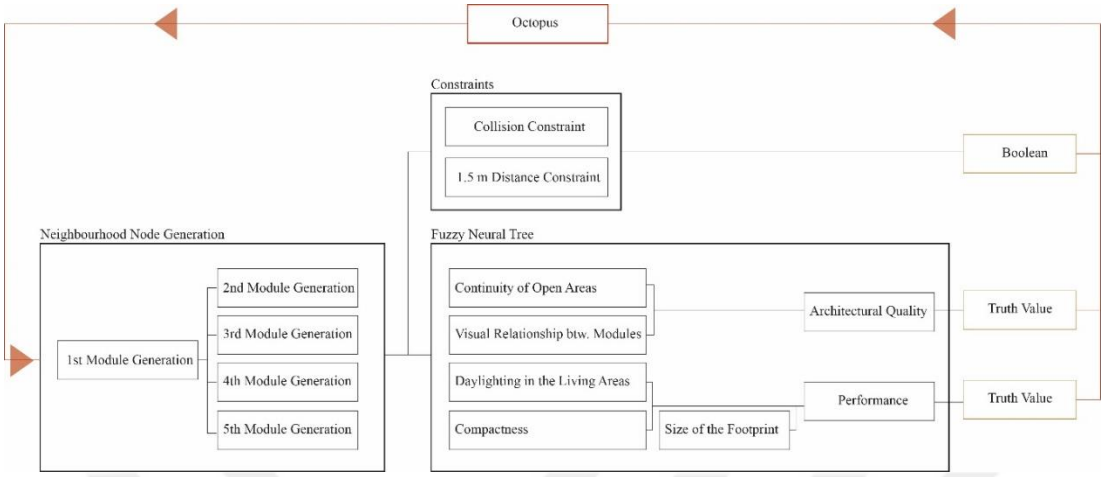


Figure 4.28: Diagram representing the Grasshopper definition of the case study.

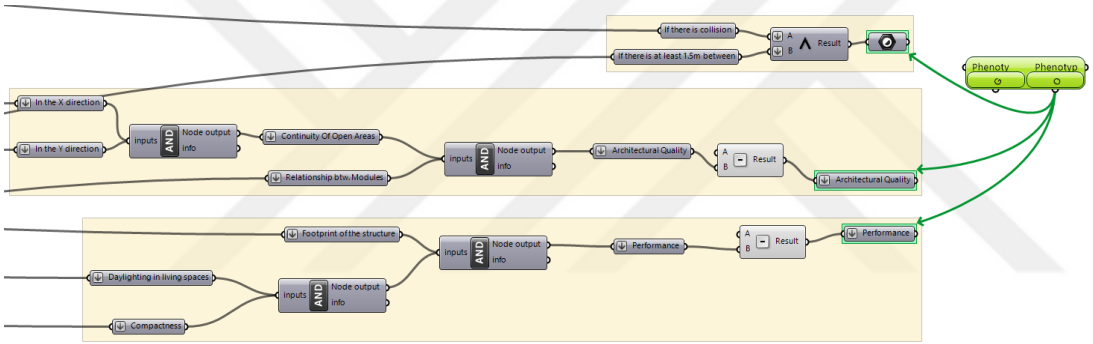


Figure 4.29: Octopus component connected to the contraint boolean and the outputs of the FNT.

The genes represented the parameters regarding growth direction for each cube, and the proximity and the position of the new modules compared to the first one. The objective functions were narrowed down to performance and architectural quality through the use of a FNT as described in the previous section. It took around 4,5 seconds for Octopus to evaluate each option. The rates determining the occurrence rate of evolutionary operations are set to certain values when Octopus interface is started. Elitism was set to 0,5, mutation probability to 0,1, mutation rate to 0,5 and crossover rate to 0,8. Population size was set to one hundred individuals. These values have not been changed as the main objective of the current study has been finding the configurations with the highest scores (Figure 4.30).

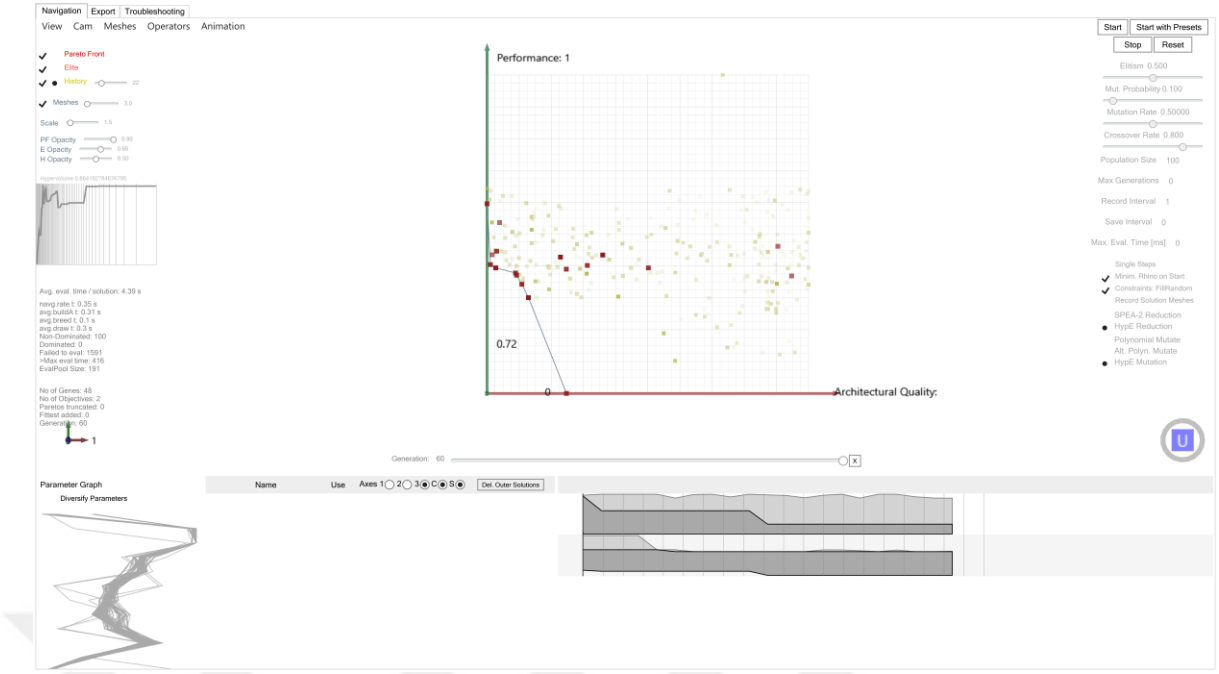


Figure 4.30: Octopus interface showing the configurations with the lowest scores.

Octopus is a MOGA interface that strives to minimize the input fitness functions. Therefore, the values of the two main objectives, performance and architectural quality, were subtracted from one in order for Octopus to work towards maximizing their value. With this in mind, every score presented in this section, represent a more desirable option as they get a lower value. As a result, eight different non-dominant configurations are obtained (Figure 4.31). It is observed that the configurations have quite better scores in architectural quality, whereas performance scores tend to be much less desirable. This means that the outputs satisfy most of the architectural quality criteria. For example, the lowest performance score out 1 is 0,823 whereas the lowest architectural quality score is almost 0. The example with the most balanced scores in both criteria is selected and a settlement pattern is created through the repetition of selected neighborhood node (Figure 4.32).

Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint and *Computational Design Process* aspects have been the base of most decisions throughtout the layout generation and evaluation phases. However in this thesis, only the process of the case study has been designed and the final outputs are generated by the algorithm itself. Therefore, it makes sense to evaluate the selected configuration with these aspects determined earlier (Table 4.1). So far, *Modularity* and *Flexibility* have been the main pillars of the design criteria. The

design sets its base onto a modular approach thus accommodating *Modularity* from the beginning. Also, the modular pieces come together to create differentiated spaces for families, presenting a solution to the repetitivity problem and achieving the *Flexibility* aspect along the way. The rest of the chosen aspects present themselves heavily in the construction phase. As the detailing part of the design process is not yet fully completed, it is not possible to fully assess the settlement in terms of *Upgrade Potential, Construction without External Help and Small Carbon Footprint.* However, it is possible to state that they will most definitely be the key points in further detailing the selected configuration.

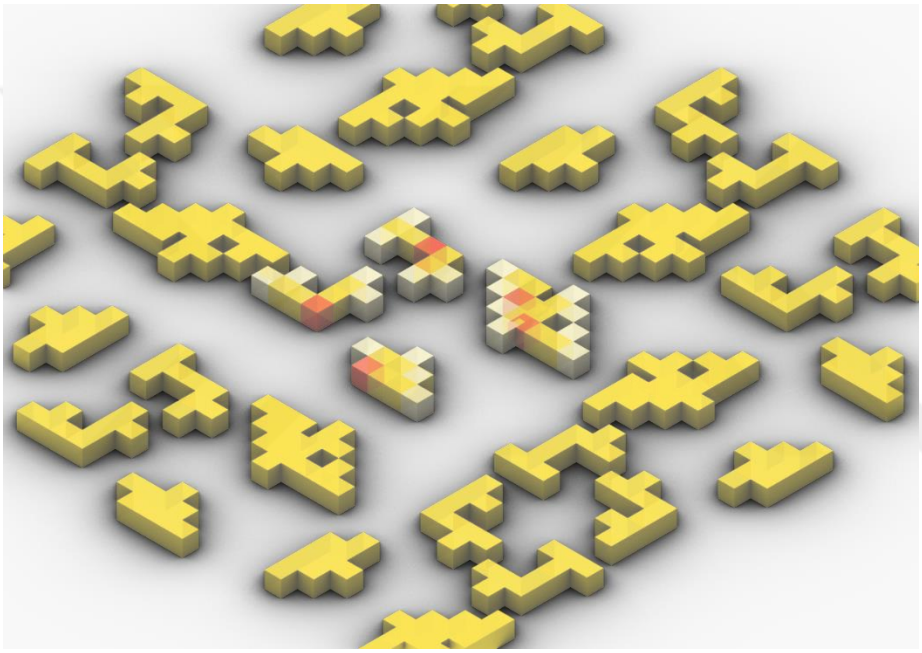


Figure 4.31: A settlement pattern created from the repetition of one neighborhood node.

Table 4.1: Case study evaluation with the aspects chosen previously.

	Modularity	Flexibility	Upgrade Potential	Digital Fabrication	Construction without External Help	Small Carbon Footprint	Computa-tional Design Process
Chosen settle-ment	x	x	?	?	?	?	x

As the structure is expected to serve in a post-disaster situation where the survivors themselves might have to build the whole structure without external help, the structural system and materials have to be quite simple and light. As described in the first main title of this thesis, one of the main requirements of the structure in question is a

transformable character to enhance the *Upgrade Potential*. So, the primary concern is the skeleton rather than the envelope itself as it can be upgraded in time as much as conditions allow. Initially, the material to cover the cube skeleton can be a plastic tent material to provide a temporary shelter from climatic condition. In time the envelope can be upgraded to modular pieces of plasterboard or wooden plates with modular options. These options can serve as a solid wall, a window opening and a doorway and they can be used as a cover for all sides of the cube. Also, the material choice can be in the direction to achieve a *Small Carbon Footprint* through the use of recycled or reused materials. The whole system can be automated in time for the construction documents and materials to be produced fastly in an emergency situation.

5. CONCLUSION

This thesis is focused on the form exploration of a modular post-disaster shelter with the use of Fuzzy Neural Tree (FNT). The main goal has been setting up a methodology where Multi-Objective Genetic Algorithms (MOGAs) can directly interfere with the algorithm that sets the rules for the shape generation and achieving the selected aspects with the generated settlement configurations. Towards this aim, aspects to look for within shelter design are chosen as *Modularity, Flexibility, Upgrade Potential, Digital Fabrication, Construction without External Help, Small Carbon Footprint* and *Computational Design Process*. These aspects set the base for the analysis of the selected examples as well as the outcomes of this thesis. They aid in shaping the algorithm that forms the pattern growth and constructing the evaluation criteria within FNT. FNT is chosen for the utmost use of MOGAs and avoiding a single-objective optimization underlying a multi-objective one. Applying this particular methodology in the design of a shelter has presented itself with a lot of potential as the outcomes turned out to be quite interesting and differentiated compared to most of the former examples within the context. As emergency situation comes with a lot of heavy requirements, the design of a shelter and the architectural quality within it, most often cannot be considered as priorities. However, the aid of a computational tool has proven itself to be useful in providing basic solutions while satisfying the possible needs of the users.

The main challenge has been the limited computational capacity which made further experimentation regarding the evolutionary operators in MOGAs a future goal for the current study. As each option took around 5 seconds to assess, the time span to reach meaningful results was not very optimal. This may be due to the inefficient construction of the Grasshopper definition or basically the way MOGAs work. As it can be observed in the graphics provided from the Octopus interface, the pareto optimal solutions did not manage to form a concave shape. Possibly, it could be formed if the system was run for more than sixtieth generation. However the bigger possibility is that the two objectives that were supposed to conflict, did not perform as expected against each other. Another solution could be using the MOGA tool named Lotus also

introduced by Ciftcioglu and Bittermann (2015) as a part of the FNT structure. Since they come in the same plugin, Lotus might have presented a more holistic and efficient optimization process. However, the constraints often resulting in *False* values prevented the Lotus component to run, stopping after a short while.

The initial step that should follow the current one is a further analysis of the materiality and construction phase. In the current state, construction and detailing are not integrated in the study and they need a thorough study to reach an efficient state. As an outcome of this phase, several different 1:1 prototypes can be constructed and they can be subjected to different climatic conditions to test their durability and suitability to the post-disaster context. Only then the results can fully be assessed with the selected aspects.

This thesis in its current state is merely a methodology exploration and form generation experiment, but it can be evolved into a holistic model that includes all the steps from conceptual design to construction. It could be connected to a user interface which would make it much more user friendly and accessible. This way, even people without an architectural education could use it with a few simple buttons to create different configurations for various disaster scenerios. The system could print out basic technical drawings such as site plans. It could output manuals for CNC cutters, and inform the users about the amount and type of materials needed to construct the structure. Therefore, it could be used even before a disaster takes place in order to prepare and store the required materials. The optimal solutions could be organized beforehand by generating possible disaster scenerios with the help of specialists of those fields. Therefore, the time needed for the optimization process could be gained in the time of the emergency.

Computational design has proven itself to have a strong potential as a tool in creating modularity, mass customization and automated fabrication, especially when the case is post-disaster settlements. Therefore, this thesis holds the potential to present a holistic digital model which can result in a design, fulfilling the requirements of a post-disaster living space.

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APPENDICES

APPENDIX A: C# Code to determine vector directions in Grasshopper

APPENDIX B: C# Code to avoid collisions when two cubes attach to the same cube

APPENDIX C: Graph showing the results of the MOGAs at different generations

APPENDIX A

```
…
Vector3d d = new Vector3d();
   if(x2 == 0)
   {     d = new Vector3d(-1, 0, 0);   }
   if(x2 == 1)
   {     d = new Vector3d(0, 1, 0);   }
   if(x2 == 2)
   {     d = new Vector3d(1, 0, 0);   }
   D2 = d;
 …
```

APPENDIX B

```
…
   List<Vector3d> vec = new List<Vector3d>();
   vec.Add(new Vector3d(0, 1, 0));
   vec.Add(new Vector3d(1, 0, 0));
   vec.Add(new Vector3d(0, -1, 0));
   vec.Add(new Vector3d(-1, 0, 0));
   Vector3d d = new Vector3d();
   if (x2 != x3)
   {     if(x3 == 0)
     {       d = new Vector3d(0, 1, 0);     }
     if(x3 == 1)
     {       d = new Vector3d(1, 0, 0)      }
     if(x3 == 2)
     {       d = new Vector3d(0, -1, 0);    }
     if(x3 == 3)
     {       d = new Vector3d(-1, 0, 0);      }
     D3 = d;    }
   else if (x2 == x3)
   {     vec.RemoveAt(x2);
     Random rnd = new Random();
     int index = rnd.Next(0, 3);
     d = vec[index];
     D3 = d;    }
…
```

APPENDIX C

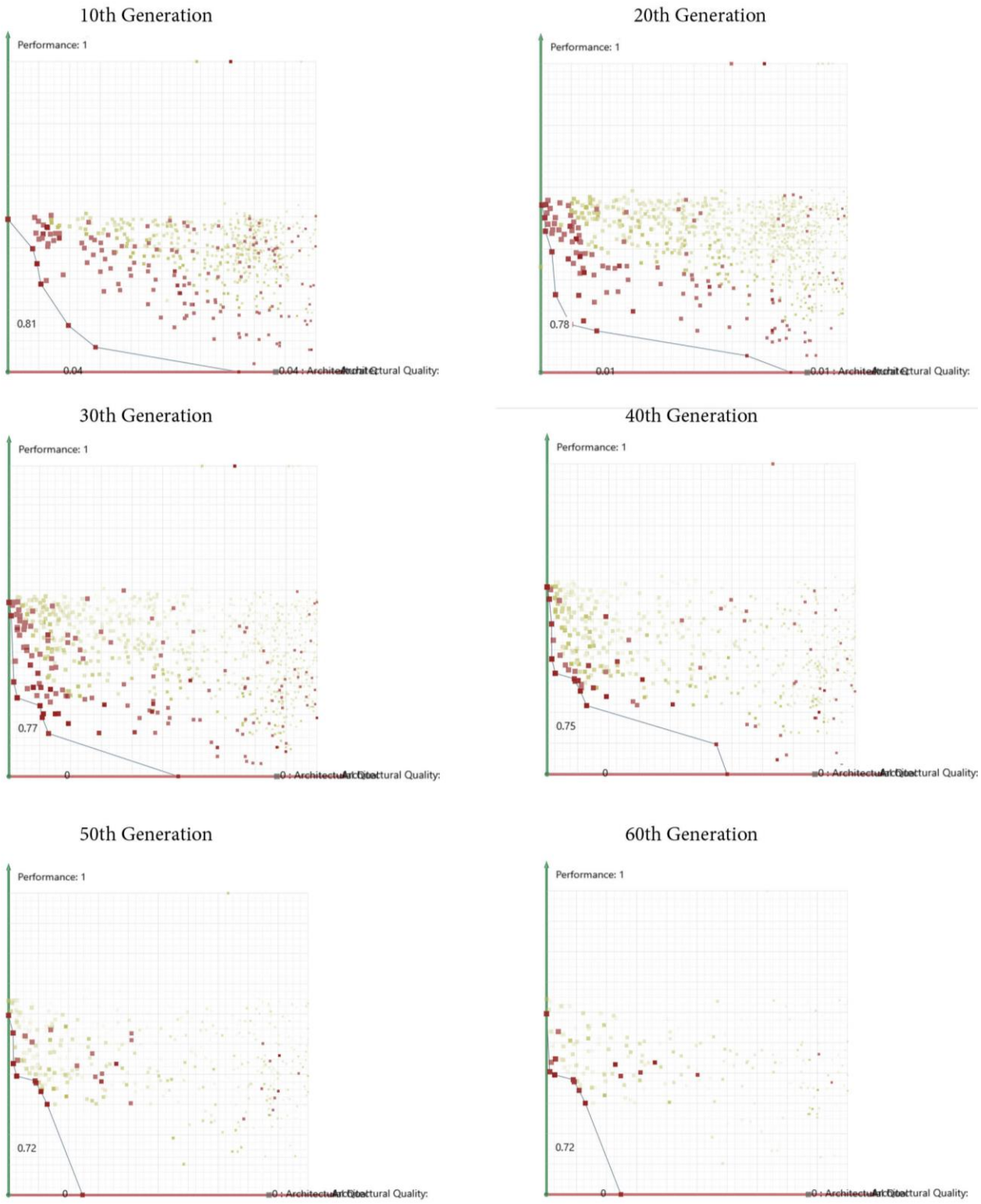

Figure C.1: Graph showing the solutions in every tenth generation in the Octopus interface.

CURRICULUM VITAE

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PROFESSIONAL EXPERIENCE

- 2010-2014 IEFT (International Education Fairs of Turkey), Simultaneous English-Turkish Interpreter
- 2015-2016 Turkeco Green Building Certificate Consulting, Part-time Graphical Designer
- 2016-2017 (1 month) Viatrans Meydanbey, Quasar İstanbul Construction Site, Intern
- 2016-2017 (8 months) Çinici Mimarlık, Istanbul, Intern and Part-time Architect
- 2018 (2 months) WE Architecture, Copenhagen - Denmark, Intern

REWARDS:

- 2012 Graduated from Darüşşafaka High School in the 2nd place
- 2012 YGS-LYS university entrance exam, 63rd in Turkey in MF-4 score type
- 2012 Entered Istanbul Technical University ranking in the 1st place amongst all ungraduated studies
- 2015 Museum of Modern Art, Uneven Growth: Tactical Urbanisms for Expanding Megacities, Project Elected for Online Exhibition
- 2016 Cemer Düşten Gerçeğe, Won 2nd prize in the playground design competition

PUBLICATIONS:

- Karaoğlan, F.C., and Alaçam, S. (2018). Design of a Post-Disaster Temporary Living Space Through the Use of Shape Evolution, 12th SIGraDI, Brazil.