Politecnico di Milano

Department ABC

ALGORITHMIC HUMANITARIAN ARCHITECTURE

ADVANCEMENT IN TOOLS AND METHODS FOR EMERGENCY SETTLEMENT AND SHELTER PLANNING

Doctoral dissertation of **Mesrop Andriasyan**

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Cycle 33

1 ABSTRACT

Humanitarian architecture is a subdomain of the architecture discipline that addresses the needs of people in an emergency for design and planning interventions. The purpose of this thesis is to illustrate the current shortcomings of humanitarian architecture practice and the developments undertaken during the research period of PhD studies that are addressed to bring advancement in this domain. The common workflows in humanitarian architecture are driven by the larger architectural practice. However, the needs of the people that are addressed here and the context in general highly differs from the conventional practice. In recent decades, there have been many advancements in architectural design technology that had a profound impact on the work methodology. Nevertheless, there has been no significant attempt to bring those advancements to the particular case of humanitarian architecture with bespoke solutions, tools and methods. The overarching question of this thesis is how can the humanitarian architectural design methodology be advanced for a better outcome for the people in need? In the pursuit of addressing this question, this thesis will present a thorough analysis of the existing situation and will present the hypotheses and solutions developed for answering it. As the title suggests, this thesis prefers to approach the humanitarian architecture task not as a design problem but rather as a calculation problem. The developments presented in this thesis are achieved mainly by the computational modelling, simulation and validation of various architecture-related phenomena like data-driven planning, dynamic form-finding, structural optimization, thermal comfort, evolutionary optimization etc. The findings demonstrate that by implementing a novel computational methodology of design and planning, humanitarian architecture can dramatically enhance its efficiency and accuracy. The thesis concludes that there is a better way of planning in humanitarian architecture and provides the necessary methods and tools to do so.

1 Abstract

1.1 DECLARATION

I declare that the thesis has been composed by myself and that the work has not been submitted for any other degree or professional qualification. I confirm that the work submitted is my own, except where work that has formed part of jointly-authored publications have been included. My contribution and those of the other authors to this work have been explicitly indicated below. I confirm that appropriate credit has been given within this thesis where reference has been made to the work of others.

1.2 COLLABORATIONS AND CONTRIBUTIONS TO AUTHORSHIP

The work presented in the chapter “7.2 Algorithmic planning and assessment of refugee camps” was partially published at thea eCAADe 2020 conference, where I was the primary author. The co-authors were my supervisor Prof. Alessandra Zanelli (thesis supervisor), Gevorg Yeghikyan from Scuola Normale in Pisa, Rob Asher and Hank Haeusler from Giraffe technologies.

Chapter 7.7, “Case study 4 – Balat settlement”, was published at Heritage 2020 conference, where I was a co-author with Prof. Marwa Dabaieh from Aalborg University. The algorithms presented in the paper were all developed by me.

The developments in chapter 8.2, “An algorithm to draw simulations of dynamic, lightweight structural systems with schemas”, were published in Tensinet 2019 symposium, where I was the single author. It was among the selected papers to have also the follow-up publication in the Journal of Architectural Engineering and Design Management, where again I was the only author. The work of the latter is presented in chapter 8.3, “Algorithmic design and evaluation of emergency shelters”.

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Dedicated to the memory of my father Professor Levon H. Andriasyan and my grandfather, Dr Hrant M. Andreasyan.

1.3 ACKNOWLEDGEMENTS

"The most important thing you will get from your PhD is people."

- **Told by someone at the PhD welcome week presentation at Politecnico di Milano**

When I heard this phrase during my first days in Milan, it occurred to me like nonsense. Being excited about the start of my PhD studies, I was mainly thinking about the knowledge and experience to be gained here. It never occurred to me that after the three years, the most valuable thing I will have found would indeed be the incredible group of people that I had the fortune to get acquainted with along the way.

My supervisor often referred to me as an independent, working PhD student. This is true in some ways; however, I cannot imagine this work being completed without the huge input from many people.

First and foremost, I would like to express my wholehearted gratitude to my main supervisor Professoressa Alessandra Zanelli for believing in me as a master's graduate and accepting me into Textiles Hub for the three year PhD research. Her trust and encouragement gave me a sense of responsibility which I believed had a profound impact on my work conduct. Under her guidance, the big family of Textiles Hub researchers had given me a sense of belonging and inspired me in many ways along the road. Among them, I would like to thank Carol Monticelli for the informative time spent in the lab together and her guidance in conference participation. Salvatore Viscuso has helped me in understanding many critical aspects of membrane architecture.

As my PhD was interdisciplinary research, I had the pleasure to work also with two prominent professors from the energy department at Polimi. Professors Livio Mazzarella and Adriana Angelotti were my mentors in the building physics domain. Only with their help, I could navigate the most complicated part of my research. I may also apologize to them for derailing the research from the path they initially intended. I hope the thesis that I wrote, in the end, will be at least of equal value to what was anticipated.

1 Abstract

My PhD career went incredibly smooth thanks to my tutor Professor Valter Carvelli, both coordinators Professor Enrico De Angelis and Professor Marco Scaioni and Ilaria Muratori, Alessandro Martinelli from the PhD secretariat staff.

Moreover, I would like to thank also the many professors from the ABC department that through their courses, taught me essential knowledge, which I used in the course of my PhD.

Thanks to Professors Martin Tamke and Mette Ramsgaard Thomsen, I had the opportunity to have long term research abroad at the Centre of IT and Architecture (CITA) at the Danish Academy of Fine Arts in Copenhagen. CITA was a big inspiration for me even before I started my PhD. The time spent there among a talented group of young researchers gave me a great deal of knowledge which, I believe, is crucial for my future. I want to express my gratitude, especially to Yuliya Šinke Baranovskaya, for the pleasant teamwork. From my time in Denmark, I would also like to thank Thomas Graabaek, the head of Graphisoft Denmark, for his support of my work.

I want to thank also all the researchers that found my study topic worthy cause of their effort and willingness to collaborate. Among them, I would like to mention Professor Marwa Dabaieh.

And finally, I would not have ever applied for a PhD without the encouragement of my family and friends. My wife Hermine was the biggest support for me from the first time I thought of doing a PhD up until the moment when I was wrapping up my thesis. I would like to thank my parents. My father, a prominent professor, was the biggest inspiration for me for becoming a researcher. Countless conversations with him about science and education gave me an enormous sense of purpose to me. Unfortunately, he did not live up to seeing my work finished.

Lastly, my friends and peers: my friend Gevorg Yeghikyan, a PhD student himself, was my constant collocutor in bizarre talks about our studies and the biggest motivator to turn my research into a work of life. I would like to also thank my dearest friend Yahya Shaker for our countless fruitful conversations and my peers in the ABC department.

1.4 DISCLAIMER

This PhD study is not supported or guided by any humanitarian agency.

1.5 GUIDE TO THESIS STRUCTURE AND READING

This research is conducted on two different scales. As the core elements of humanitarian architecture are emergency settlements and emergency shelters, some of the chapters have this division. The main research is also presented in two sections. Figure 1 describes the overall structure of the thesis. As shown in the diagram, some chapters refer to the different scales of settlement and shelter.

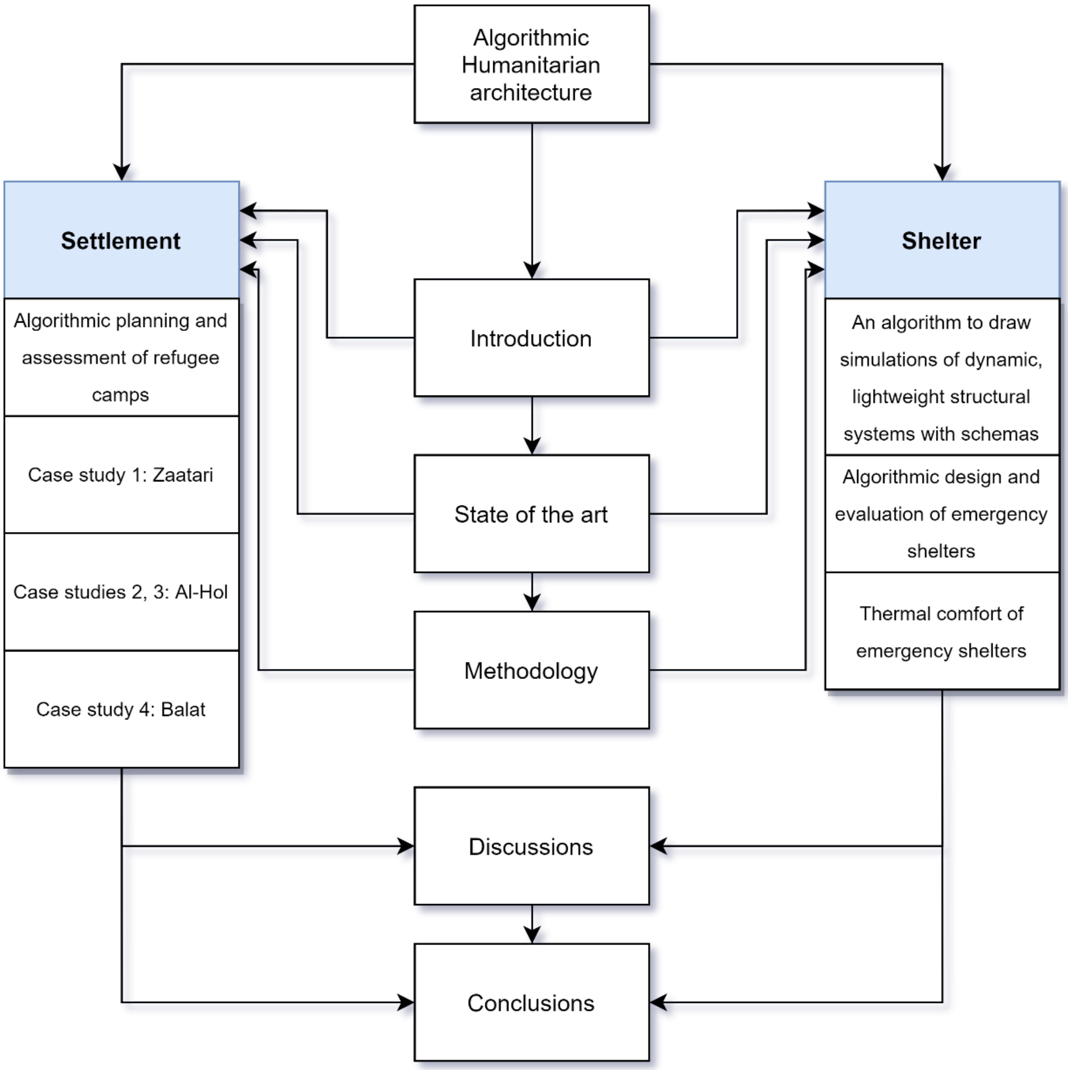

Figure 1 Reading structure diagram

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2.1 LIST OF FIGURES AND TABLES

2.2 OFTEN USED ABBREVIATIONS

AEC – Architecture, Engineering and Construction

BIM – Building Information Modelling

CAD – Computer-Aided Design

CCCM – Camp Coordination and Camp Management

GAE – Graphical Algorithm Editor

GBV – Gender-Based Violence

IDP – Internally Displaced Person

IOM - International Organisation for Migration

NFI – Non-Food Items

NGO – Non-Governmental Organisation

OCHA – United Nations Office for the Coordination of Humanitarian Affairs

OSM – Open Street Map

UNHCR – United Nations High Commissioner for Refugees

WASH – Water, Sanitation and Hygiene

2.3 USE OF TERMINOLOGY

Unless explicitly noted otherwise, the following terms will have the below-mentioned meaning throughout the thesis.

Settlement – The term will always refer to an emergency urban structure that is a result of an amendment to an existing urban structure or a new one built from scratch. Even if written ”settlement”, the reader should understand it as ”emergency settlement”.

Shelter – Architectural object, provided or self-built for the purpose of serving as a place to live for the people that are in need of humanitarian intervention. There is a convention in the humanitarian field on the term Transitional Shelter which refers to a process, not a physical object. This thesis will always refer to the shelter as an architectural object.

Plot (as a noun) **/Shelter Plot** – A piece of land dedicated to being used by the inhabitants of one particular shelter. Not necessarily circumscribed by any physical boundary.

Generative design – A process carried out through a set of programmed procedures that generate geometry or data.

Parametric design – A process or a product of a design procedure where the geometry or data are linked to certain parameters.

Algorithmic modelling – A set of procedures linked to each other where the generated geometry or data of one procedure is a variable for another one.

Form-finding – A procedure to determine the final shape of an architectural object as a result of various internal and external factors and forces.

Designer/site planner/urban planner/architect/operator – These terms may be used interchangeably to describe the person that performs the design, decision making or planning activity.

Genome – A variable parameter in a system that changes the output

Phenome – Any data whose changes are tracked when genome is changing

3 INTRODUCTION

This introductory chapter will describe the premises of the research, will point out the research niche with the existing knowledge gap and will explain the significance of the research.

3.1 HUMANITARIAN CONTEXT

As it is described in the Annual Disaster Statistical Review 2016 [1], from 1990-2016 years, the mean number of deaths from natural disasters increased until 2005 and then it started dropping down until 2016 (Figure 2). This is a good tendency; however, the number of people that were affected by the disasters did not go down but instead kept continuously increasing until now (Figure 3). Furthermore, the statistical data shown by UNHCR [2] portrays an even more drastic increase in the total number of Refugees and IDPs (Figure 4) that are again a subject of great concern. According to the Global Humanitarian Overview [3], there are more than 135 million people in need of humanitarian aid. This includes the need for shelter.

Despite all the notorious efforts of the humanitarian agencies to mediate the effects of disasters and conflicts, the total number of people that need humanitarian assistance is still growing.

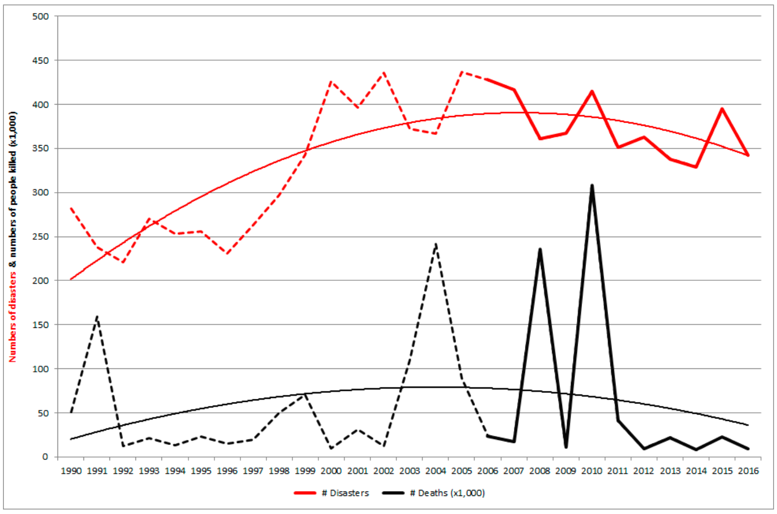


Figure 2 Numbers of disasters and people deaths (x1,000) 1990-2016 [1]

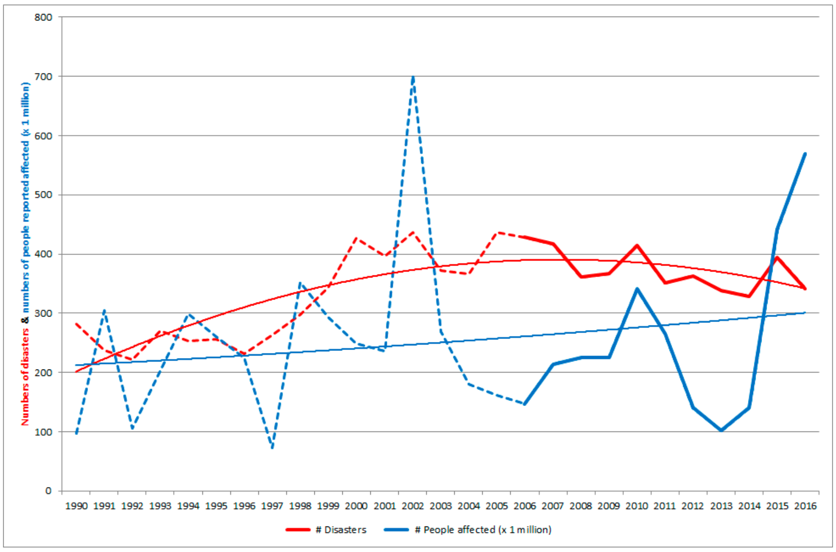


Figure 3 Numbers of disasters and total people reported affected (x 1 million) 1990-2016 [1]

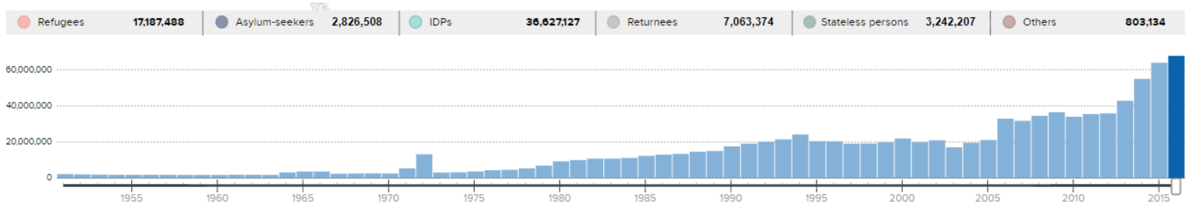


Figure 4 UNHCR statistics [2]

If we think of the generalised description of people in need of humanitarian architecture, a particular group of these people are the refugees.

Emergency related to refugees is somewhat different from the emergency related to disasters and other causes. One inherent trait of refugee responses is that quite often, the timespan of the refugee crisis is indeterminate. Another difference is that if an emergency happens in the form of a disaster, for example, the affected population receives an immediate and effective response from the government, whereas the Refugee crisis normally happens in the areas where conflict is present or if the people have enough reasons to flee their own country. This eventually places them outside of their homeland and means that the people are in the hands of the hosting country and acting humanitarian agencies. Another important characteristic of a refugee is that it implies the movement of a person from the place of residence to somewhere different. This is particularly important in this research. That brings a change of the urban context and the change of living conditions that the person had.

This research has the following hierarchy. It lies within the context of humanitarian response as the Broad topic. Still, it is an architectural study and investigates humanitarian architecture. It is addressed to the planning for refugees. The core of the study is about emergency settlement and shelter planning. The Figure 5 diagram depicts the hierarchy and the importance of the topics in the premises of this research.

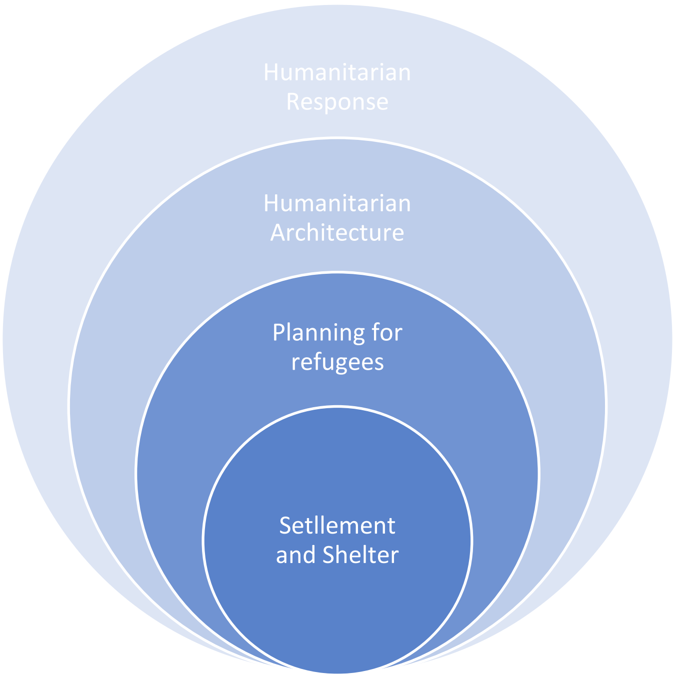


Figure 5 Hierarchy diagram

To describe the general framework of the current study and to settle the governing humanitarian principles for accountability, the "Humanitarian Charter and Minimum Standards in Humanitarian Response", more widely known as the "Sphere Handbook", will be addressed [4]

More specifically, the chapter to which this study will occasionally refer is the chapter on Shelter and settlement [5].

As this study will include potential shelter designs and technical solutions, the key provisions of the shelter described in the diagram from the Sphere Handbook will be kept as a guideline.

3.2 HUMANITARIAN ARCHITECTURE

The subdomain of architectural practice that deals with shelters emergency settlements is humanitarian architecture. Humanitarian architecture is a term often used to describe architectural design activity carried out to meet the needs of people in the urgent necessity of it that are not immediately capable of affording and conducting such service. The usual workflow of conventional architectural practice starting from the commissioning until the end of the project highly differs from that of humanitarian. The “client” here is the vast amount of people that, in a short time-lapse, has suffered the loss of their livelihood and quite often are on the verge of existence. In this regard, humanitarian architecture prioritises design qualities that are of direct impact on the occupant. There can be no architectural context in which it is more important to get the human dimension absolutely right than in creating emergency shelters [6].

Humanitarian architecture also differs in the following terms.

The people that use the product of the humanitarian architectural design are not usually the ones that commission the job of doing it. Instead, it is done by the humanitarian agencies, local governments and NGOs. This often brings the discrepancy between what was instructed and what do people need. Although this way of things has its intrinsic problems, it remains the prevalent method of delivering humanitarian architecture service to those in need. There is an ongoing process of bridging this gap. Several major actors in the industry have developed and refined standards and guidebooks to provide a benchmark for architects. It is asserted in [7] that there is no one size fits all design method in humanitarian architecture and that local culture and characteristics should always be adopted when designing a shelter/settlement. However, there is also a big amount of criticism [8] towards those major actors saying that they try to force one solution to every case. The enforcement of the same standards in all cases leads to a totalitarian environment that does not reflect the community living within. On the other hand, the absence of governing principles and aid brings to chaos. For example, the non-compliance to density standard will lead to cramped living conditions and over-population, which may have devastating consequences. A terrifying example of this can be witnessed in the Moria camp in Greece, which was qualified by BBC as “the worst refugee camp in the world”. The exaggerated it may seem, Moria had suffered a great loss of order after some humanitarian agencies revoked their services from there, leaving the responsibility to the Greek government. As a result of the overcrowded camp, there has been a significant rise in suicide attempts among children [9].

The role of the humanitarian architect for forming the environment where the people in need will live is very important. The humanitarian architect leverages the standards and guides implied from the top and demands and concerns coming from the bottom.

One of the world's leading authorities on humanitarian aid Kilian Kleinschmidt notes:

“I think we have reached the dead-end almost where the humanitarian agencies cannot cope with the crisis. We are doing humanitarian aid as we did 70 years ago after the second world war. Nothing has changed.” [10]. The exaggerated as this statement may seem, it still has a great amount of truth in it, especially in regards to humanitarian architecture.

On the other hand, we cannot say the same about the conventional business of architecture. There has been an immense leap forward in how things are done in commercial architecture, particularly in the use of technology. Like any other industry, here again, the progress is happening at an increasing pace. Nevertheless, somehow, this progress does not touch the humanitarian architecture to the extent that it does other domains of the industry. This thesis aims to bring the development in the technology of architectural and urban design to humanitarian architecture.

3.3 SETTLEMENT

One of the major components of an emergency response is the settlement. In the case of refugees, it can be the refugee camp. Although refugee camps are always advised to be only as a measure of last resort but quite often, we can see that the crisis ends up with people living in such camps. In some cases, people may live there for more than a decade. Those camps become permanent settlements. As mentioned above, the Refugee camps may have an indeterminate lifespan, so the planners in humanitarian architecture should start with the notion that whatever they are planning, it should be well designed for a long term period. They also undergo many changes over time. So given that there are many guidelines on how a well-conducted refugee camp should be, there is a necessity for constant checks on how the camp is performing as a settlement. As this thesis will further demonstrate, there is a shortage of tools and methods of making such checks.

The current situation of refugee camps as urban structures are highly rigid. It seems that all of the Refugee camps are a copy of one another to a certain degree. The reason is that the governing entities that decide how the camp should look like or where a specific type of facility should be positioned make certain standards that end up being replicated all over places. A very vivid example of this is the urban layout of refugee camps which most of the time have a very modernist grid structure. There are several reasons why grid structure is considered to be well-performing. Such as being easy to plan, easy to deploy and easy to monitor. However, there are also many reasons to think that such an urban structure is a wrong solution. One such important aspect is that the grid structure does not take into consideration the background of the people that are going to reside there. For example, if the incoming population is coming from a Muslim background in a hot climate where they used to live in cities with convoluted narrow alleys, small courtyards and covered streets, it may be a very daunting experience if they continue to leave their lives in a space where every house is 100% replica of the neighbouring house, and the streets or neighbourhoods are indistinguishable one from another.

An outstanding example of such a phenomenon is the Azraq refugee camp in Jordan (Figure 6). Although it is a relatively recent settlement that adheres to perhaps all the existing guidelines and planning principles, it does not make the inhabitants feel good and feel safe there. Many refugees that were invited to live there have rejected it whatsoever.

3 Introduction

There has been a lot of criticism towards the planning principles of refugee camps in recent years. The criticism comes not only from the dwellers but also from the practising professionals in the field. For sure, there is a place for critique. Still, one key consideration must always be taken into account, which is that the planning practice of refugee camps is entirely different from the regular planning practice that an architect might have in a conventional working environment. The crucial thing that may affect the design is time. Since it is an emergency and some people are in urgent need of a place to live quite often, the planners and architects prioritise quick and short-term effective solutions as opposed to more deliberately planned and long-term solutions. As a result, we find the newly designed refugee settlements being just a grid layout with the placement of amenities that are just there to comply with the defined standards.. As such, there is not much time to take into consideration the wishes of the people that are going to leave there or to study their background or to test whether the given solution is appropriate at all or not.

This thesis seeks to understand the existing planning principles of emergency settlements end to identify the gaps of practice that lead to inadequate performance solutions. Planning of emergency settlements is one of the core sections of this thesis which provides a big set of methods and tools to design and assess settlements such as refugee camps.

Figure 6 Azraq camp in Jordan [11]

3.4 SHELTER

The second main section of this thesis is about shelters. In the early stages of emergency response, one of the prominent types of shelters provided to refugees are the emergency tents. Here again, we can witness solutions that are based on the same guiding principles defined by humanitarian agencies such as UNHCR. An example of such a ubiquitous solution can be the family tent developed by UNHCR. The same issues described above also apply when it comes to shelter design. Very short time span and the status of emergency urges the designers to go after readily available solutions and to neglect the characteristics of the affected population and their needs.

If we have a closer look at the structure of those emergency tents, several unusual structural peculiarities instantly appear. The shelters are often composed of soft membrane skins that are tensioned with cables and are supported by either rigid or bending active [12] elements. Those types of structures are considered unconventional in architectural practice due to a particular structural behaviour and design methodology that does not always follow along a usual design process. Soft structures used in emergency sheltering such as membranes, tarpaulins, awnings, cables, and tendons are geometrically active, and they change shape during the construction, usage and dismantling. This shape change is very challenging to the architects and designers since they need to be aware of and capable of controlling that change in geometry. The earlier methods of addressing this task were based on model creation, soap film experimentation and other activities that yielded geometry deformations of a structure close to what the architect expected from a design. Those methods helped renowned architects such as Gaudi or Frei Otto to erect some of their magnificent buildings. However, their conveyance of useful information was limited by the mere geometry at hand.

Recent developments in computational modelling and the ever-growing interest of architects to perform various simulations in their field have brought new sophisticated and data-rich methods for design simulation and analysis.

The thesis presents an environment modelled utilizing cutting-edge architectural computational modelling tools to help humanitarian architects to design emergency shelters of dynamic structural nature intuitively and to obtain instant geometric and structural performance analysis.

3.5 COMPUTATIONAL MODELLING IN ARCHITECTURE

As mentioned in the previous section, this thesis utilises the broad methodology of computational modelling in order to find better solutions for humanitarian architecture end to establish new methods and instruments that can be used by the planners.

In the past three decades, architects have come to use programmable mathematical principles to define forms and spaces in their designs. These methods are often recognised under the term parametric architecture and bring images of complex geometrical forms that the architect alone would not have been able to draw or model. In the architectural industry, the parametric or algorithmic terms provoke a notion of a particular style in architecture, such as works by Zaha Hadid, Greg Lynn and others. It also implies a bias of something costly. In the process of the research presented in this thesis, the algorithmic and parametric modelling is not addressed as a tool to achieve eye-catchy aesthetics but rather as a modelling and assessment toolset to help practitioners perform better in humanitarian architecture.

3.5.1 ALGORITHMIC FORM-FINDING

Form finding is a procedure to determine the shape of equilibrium of the desired prestress state and the boundary conditions (Stranghöne & Uhlemann, 2016). It is found that the behaviour of the investigated bending-active (form active) structures does not fall into clearly predictable categories; their load-bearing is mainly dependent on the variety of topologies and geometrical expressions that may be generated. Similarly to membrane structures, the geometry must be form-found; in this case, simulating the elastic bending deformation [12]. Ultra-lightweight structures of which refugee tents are commonly made often include form-active components that have large deformations and complex forms that are difficult to model with conventional 3D modelling processes. In recent years more and more attention has been given to visual programming platforms to develop more complex geometrical solutions. A significant step forward is the emergence of simulation engines that help to create dynamic simulations of different structural behaviour. Even though some use arbitrary values and does not provide accurate structural data, it much helps in understanding how a specific type of structure might behave. Figure 7 represents the flow chart of the described form-finding workflow.

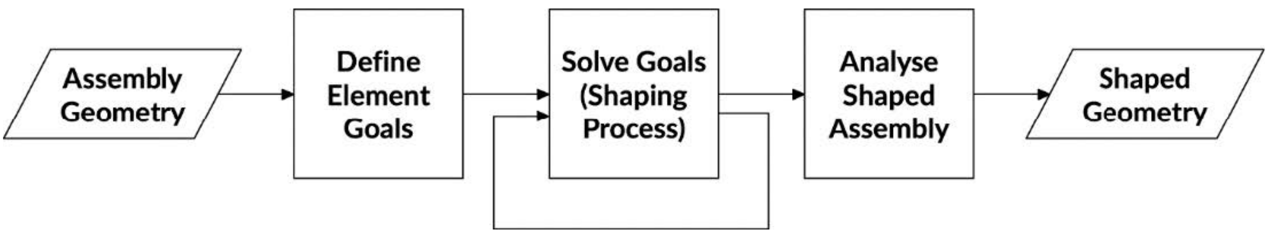


Figure 7 A design modelling pipeline using the Kangaroo2 library [13]

Graphical algorithm editors (GAEs) allow the coupling of different disciplines with each other within the same workflow. This thesis has several examples of such coupling techniques.

Those include but are not limited to:

- Form-finding + Structural analysis
- Generative modelling + Thermal comfort analysis
- Generative modelling + Geometry analysis + Data visualization

3.6 SIGNIFICANCE

As the number of people that require humanitarian architecture as a service grows, the knowledge base and the tools used to meet this requirement should grow as well. This thesis aims to contribute new methods and instruments for humanitarian architecture and for humanitarian response in general.

In recent decades there has been much advancement in the design technology and methodologies put into use in the larger architecture, engineering and construction (AEC) industry. Namely computational modelling and algorithmic design. However, the progress is more laggard towards humanitarian architecture. Despite a few attempts in the use of cutting-edge technologies and few research articles, there is no wide adaptation for algorithmic planning for the displaced populations.

4 STATE OF THE ART

4.1 MAJOR ACTORS IN HUMANITARIAN AID

The first procedure for outlining state of the art was to find and recognise the leading actors in the field of humanitarian response. As it is described in the Table 1 matrix from OCHA, there are two main clusters assembled to deal with the issues of settlements and shelters, respectively. Depending on the type of context, whether it is a natural disaster or conflict, a different agency may take the lead of actions such as the IFRC or UNHCR. These two clusters have online databases of resources that contain reports and case studies that closely portray the situation of humanitarian response that we have now [14].

Table 1 Management matrix from OCHA

CLUSTER	CONTEXT	LEAD AGENCY
CCCM	Natural Disaster	IOM
	Conflict	UNHCR
Shelter	Natural Disaster	IFRC
	Conflict	UNHCR

The two clusters together have published resources to guide humanitarian response, including guidelines and standards for architects and urban planners. The developments here are mostly from after the second world war. Despite the huge work, there is a place for advancement. Some of the standards are very shallow. As shown in the later chapters of this thesis, some are ambiguous, require better definitions and may differ from case to case.

Also, The information needed for architectural and urban design of emergency settlements and shelters is scattered among different documents published by different entities. One such big publication is the guidebook “Transitional settlements: displaced populations” [15]. There is a chapter dedicated to urban scale design. However, the book is intended for a broader audience hence is less specific about architecture.

4.2 ANNUAL REPORT ANALYSIS

The two clusters publish case study reports for both emergency settlements and shelters [16]–[18]. As a part of the literature review, around 50 case studies (13.1, page - 144 -) of emergency responses were investigated in order to determine the materials and sheltering solutions that were implemented. Those are emergency cases that are relatively well documented and have an organised strategy of response. The case study investigation's aim was to withdraw the particular information concerning the dimensions, materials' choice and technical specifications of the shelters. During the investigation, it turned out that some materials are more likely to be used in an emergency response than others, regardless of the geolocation of the emergency. Among these, plastic sheeting seems to be the most omnipresent material that is widespread due to its low cost, versatility in use and durability.

Important facts that were discovered from the case studies:

- The first responders to the emergency are always the affected people. Also, they are responsible for the major part of the construction works that take place. This leads to the notion that sheltering solutions must be low tech.
- Emergency shelters are often reused, especially in the occurrence of disasters within the same country or region over a span of short time. This means that the shelters must be reusable.
- Above 90% of cases, the emergency shelters are designated for single-family use
- On average, they have a 17 sqm area
- The internal comfort issues are not properly addressed. In particular, the thermal insulation layers rarely exist in emergency shelters.
- Plastic sheeting is included in the majority of emergency responses. However, its use is often limited to the imagination of the end-user. It is not on every occasion that this material serves as a structural asset and performs sufficiently.

The last point is particularly interesting since the development for the possible new ways of the usage of plastic sheeting will bring new solutions to the industry without much spending and might be retrofitted into existing camp structures as well.

4.3 ALGORITHMIC MODELLING FOR HUMANITARIAN ARCHITECTURE

Computational modelling in architecture is a relatively new domain. The literature and knowledge here are still in the early stages of development. The reason is that only in recent years have the computational capabilities used by architects evolved enough to be able to handle large amounts of geometry and data. Computational modelling in humanitarian architecture is even rarer.

4.3.1 Settlements

The biggest attempt to bring computational modelling to the task of planning an emergency settlement was performed by a joint effort of UNHCR Stanford University and Ennead Lab [19]. This work was also reflected in detail in the work by A. Huynh [20]. The key message in both works is the discrepancy between the planned and actual longevity of emergency settlements. The project is not open source. The information available about how the toolkit is developed is very limited. No public reports on the toolkit performance have been found during this research. However, it was evident from the available limited presentation materials online that they utilise similar methodology and tools as used in this research. The pace of advancement in the field of computational architecture is very fast. Some of the libraries and methodologies used in this thesis have been developed after this publication. This means that the advancement in algorithmic humanitarian architecture should be continuous. This thesis combines some of the cutting edge technologies in computational modelling. Therefore it is expected to push forward the state-of-the-art.

Another similar work but on a smaller scale was published by E. Daher and S. Kubicki [21]. This paper is another stepping stone in bringing computational modelling to humanitarian architecture. The paper proves it possible. However, their model is very simplistic. It is a one-case experimental study. In other words, using their method will always result in similar plans.

4.3.2 Shelter

Algorithmic modelling methods have been continuously implemented in recent decades in the fields of architecture and urban planning. In regards to humanitarian architecture, the implementations were more to the side of shelter design rather than settlement design. Many of the existing advancements are parametric models of various shelters [22]–[25] or standardized camp models [21].

Notable work is done by textile architecture researchers from Politecnico di Milano [25] that has some common methodology with this research. However, their work was more focused on a specific design task, whereas this research presents a more generalised workflow for shelter design.

4.4 ALGORITHMIC FORM-FINDING

One of the states of the art research methodologies that had a great impact on the form-finding methodology presented in this thesis is the work done by Centre for IT and Architecture researchers [13]. Their paper has nothing to do with humanitarian architecture, but a novel approach to design and form-finding is shown. The key outcome of the paper is to show that the design and form-finding procedures can be coupled together in one continuous algorithm. Several workflows in this thesis are similar to what has been done. The research provided in the Shelter section (8.2, page - 100 -) has begun with a partial replication of this study. In this thesis, their algorithm was more generalised to incorporate more structural elements and properties. Structural analysis was incorporated into the workflow. Lastly, the algorithm was tailored to the use of humanitarian architecture. Compliance with standards is tested, and dynamic analysis is performed as the designer designs the shelter.

4.5 RESEARCH IN TEXTILE MEMBRANE STRUCTURES FOR EMERGENCY

As was discovered through the case study analysis (4.2, page - 30 -), membranes are a key component for shelter design. In this regard, a literature review was conducted on the use of architectural membranes for emergencies.

In a general discussion about the membrane structures, there are several groups of experts that have been working on getting all the bits and pieces of knowledge that were implied across various projects to assemble in a unified guidebook. The fruitful results of such meticulous research works are the European Design Guide for Tensile Surface Structures (2004) [26] by TensiNet and the Prospect for European Guidance for the Structural Design of Tensile Membrane Structures (2016) [27] by JRC. These two guidebooks are also a big step towards creating standards and regulations for this domain.

If we narrow down the subject to focus more on the issues of emergency sheltering, we can see that only a few institutions and researchers exist that focus on the topic from the humanitarian point of view. One of the major actors in this field is, of course, the UN's subsidiary UNHCR (United Nations High Commissioner for Refugees), which provided a significant amount of development in this field.

From March 2012 - to February 2016, a research was developed named S(P)EEDKITS, that incorporated several parties to improve the current level of development for emergency sheltering [28].

Another initiative that is dealing with housing for displaced people is BetterShelter, which is cooperating with UNHCR and IKEA to design, prototype, test and implement better solutions for emergency sheltering.

In RMIT(Royal Melbourne Institute of Technology), there is a group of experts called HARB (Humanitarian Architecture Research Bureau). Their aim is to bring a multidisciplinary approach and gather different professionals (architects, engineers, etc.) to work on sustainable solutions for emergency housing.

Global Shelter Cluster is a coordination entity that, in hand with IFRC and UNHCR, assists in emergency housing responses. Each year they publish a case study overview that describes the shelters developed across the world.

CLUSTEX in Politecnico di Milano deals with textiles structures with a particular focus on emergency sheltering. Several articles have been published in recent years by member experts. The hub also carries out structural tests for textiles.

4.6 THERMAL COMFORT OF EMERGENCY SHELTERS

From the two main handbooks described above, a summarized explanation of thermal characteristics for these structures is only present in the first one [26].

The Sphere Handbook, as a result of numerous knowledge contributions and case studies, has composed guiding principles to follow in the shelter design task. Although they contain no technical details or specifications, they can be useful in the quick understanding of the context and the directions to follow while searching for solutions. Below are excerpts of scenarios regarding decisions for various climates:

”In warm, humid climates, design and orient shelters to maximise ventilation and minimise entry of direct sunlight. A higher ceiling helps air circulation. An attached covered outdoor space helps reduce direct sunlight and protect from rain. Consider the use of adjacent shaded or covered external space for food preparation and cooking, with separate space for other living activities. The roof should be sloped for rainwater drainage with large overhangs, except in locations vulnerable to high winds. The shelter construction material should be lightweight with a low thermal capacity, such as timber. Use raised floors to prevent water from entering the covered living area.

In hot, dry climates, heavyweight construction material (such as earth or stone) ensures thermal

comfort despite changes in night and day temperatures. Alternatively, use a lightweight construction with adequate insulation. Pay attention to the structural design of heavyweight construction in seismic risk areas. Provide shaded and ventilated places where possible and appropriate. If only plastic sheeting or tents are available, provide a double-skinned roof with ventilation between the layers to reduce radiant heat gain. Position door and window openings away from the direction of the prevailing hot wind. Internal flooring should meet the external walling without gaps to prevent dust and disease vectors from entering.

In cold climates, a lower ceiling is preferable to minimise the internal volume that requires heating. Shelters occupied throughout the day require heavyweight construction with high thermal capacity. For shelters only occupied at night, lightweight construction with low thermal capacity and substantial insulation is more appropriate. Minimise airflow, particularly around door and window openings, to ensure personal comfort while also providing adequate ventilation for space heaters or cooking stoves.

Adequate ventilation helps maintain a healthy internal environment, prevents condensation and reduces the spread of communicable disease. It reduces the effect of smoke from indoor household stoves, which can cause respiratory infections and eye problems. Consider natural ventilation where possible. ” [29]

Below studies are practices of various researchers to examine the topic.

One of the first attempts to assess the internal thermal environment of the emergency shelter is the test by engineers from Cambridge University [30] in 2002, among whom was Peter Manfield, that has made a significant effort in emergency sheltering research. The physical test was carried out with the external temperature of -20 Co. The internal comfort was registered through a set of sensors that were distributed across the surface and inner volume. Later on, the physical model tests were calibrated into a simulation test and further, the tent model was tested with the climatic data of Islamabad, London and Pristina. This was one of the first attempts at using the computer simulation for emergency shelter assessment (Figure 8). In their tests, they revealed one of the dominant problems that occur in emergency textile shelters. As below mentioned:

- The temperature shows a dramatic difference in height.
- Without proper insulation, it is unlikely to achieve internal comfort by mere casual thermal gains.
- During peak activities inside the tent, the humidity can get to its maximum

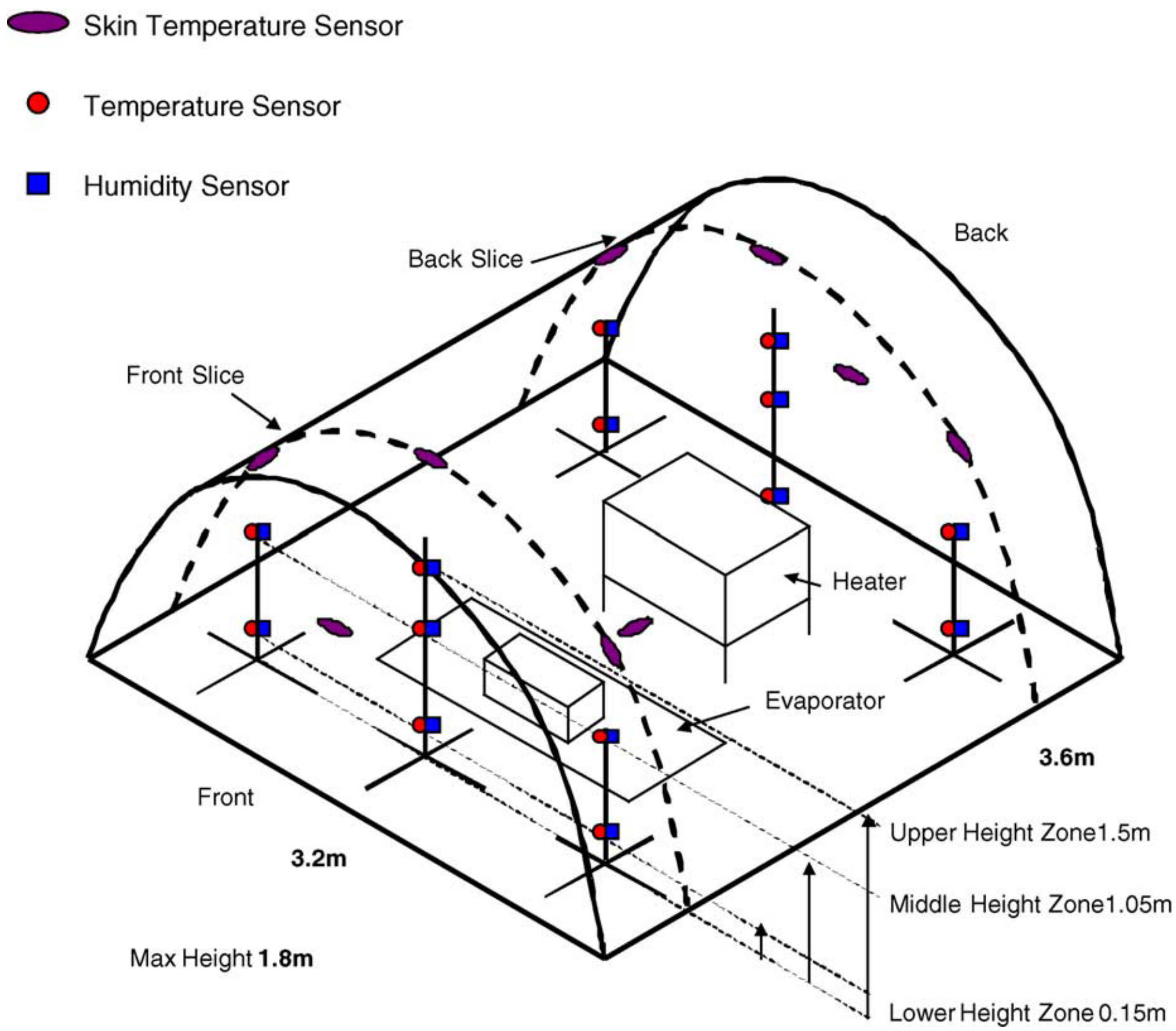


Figure 8 Tent Sensors [30]

Several other attempts occurred in recent years. In 2013 engineers from the University of Rome Tor Vergata, have tried to develop a different solution for the emergency tents in order to improve internal comfort [31]. Pursuing this, they assembled a tent and tested its performance during May 7-15. Then the received information of the physical test was used in the greatest details to calibrate a simulation model for the same period (Figure 9). Furthermore, later on, the calibrated model was tested with different solutions of design and materials in Torino (winter) and Palermo (summer). Their research shows that by adding high insulating material (aerogel pad) and a particular treatment of the floor, a better internal environment can be achieved. This will dramatically decrease the energy demand for the tent.

Figure 9 One site calibration tent [31]

A very interesting approach can be seen in the research and implementation project by Clustex/Politecnico di Milano researchers [32]. Together with S(P)EEDKITS, they have developed three different solutions with the use of textiles that were later given scores on various performances (Figure 10). The thermal comfort of the most promising solution was tested with the weather data of Ulaanbaatar (Mongolia), Tabriz (Iran), Damascus (Syria) and Dakar (Senegal). The winner concept was prototyped in ten units and tested by Senegal and Luxembourg Red Cross delegations.

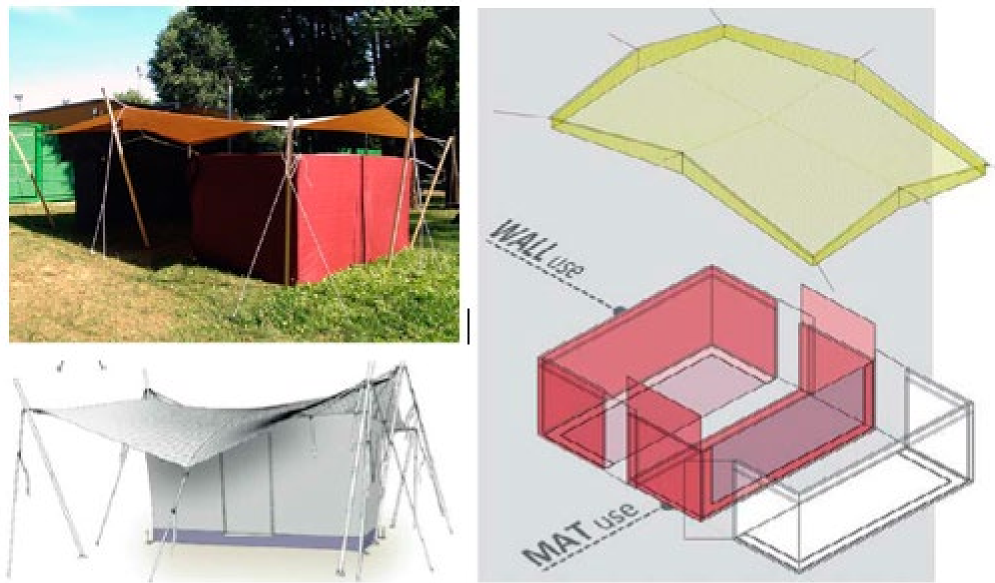


Figure 10 3 Initial solutions [32]

Probably one of the most sustainable solutions in this field was proposed by researchers from Politecnico di Milano [24]. The concept was to collect the disposed skis that accumulate in significant quantities each year and are not a subject of recycling and to implement them as a construction element inside an emergency shelter (Figure 11). The designed ski yurt-like structure was enveloped by multilayer composite that was in a double PVC layer, both outside and inside, with a thermo-reflective insulation system interposed in between. Later on, the design was simulated for the thermal comfort analysis with the climate data of Palermo. The shelter was assembled in Italy, then disassembled and sent to Guinea Bissau. In terms of internal comfort, it was suitable for hot climates. The notable thing here was the chimney effect that due to the opening in the highest point could let the hot air out of the tent and thus not cause the height temperature variance as it usually happens with the vaulted tents without a skylight opening.

Figure 11 Ski shelter [33]

One of the few research works that showed a backward approach is the analysis by Obyn et al. [34], where instead of just doing the simulation for different climatic zones, they actually did investigations on the real tents in different climatic zones (Brussels in Belgium, Sag Nioniogo in Burkina Faso and Bertrange in Luxembourg). They used the famous and omnipresent family tent (Figure 12) from the UNHCR core relief items catalogue [35] to see how it actually performs. Afterwards, they made the corresponding computer simulations, and the compare results were quite accurate. Also, a good methodology for such kinds of assessments is described.

Figure 12 UNHCR family tent [36]

It is worth mentioning that not all the designed shelters are ending up in the emergency field. Among the ones that actually are being implemented, not all the tents are being monitored to see whether they are performing well or not. Among the ones that are currently under monitoring is the Multipurpose by Clustex researchers together with IFRC and Ferrino that have been sent to Burkina and Senegal Burkina to serve.

Figure 13 T2 multipurpose tent [28]

4.7 LITERATURE REVIEW CONCLUSIONS

By analyzing the above-given research literature and investigations, we can say that there is slow progress to bring computational modelling knowledge to humanitarian architecture. The existing developments are limited. No wholistic study is present at the moment.

Despite several attempts to demonstrate the potential of such technologies, the prevalent methodology for humanitarian architecture still remains in the realm of traditional CAD or BIM. It can be done better.

The studies of textile emergency shelters' internal environment are very recent and progressively are entering into the realm of computer simulation and weather data-driven analysis. As we see in the examples of thermal assessment, the computer models can be very well calibrated with the real shelters and give enough accurate results. However, the post-implementation data of comfort for such tents are limited, and long-term evaluation of these objects are required to see whether the initial design anticipations do really match with the actual performance or not.

On the other hand, in recent years, more and more tools are becoming available for researchers for computational urban/architectural planning and comfort simulation. These tools continuously improve the accuracy and ease of use.

The weather data is increasingly accumulating in platforms such as ASHRAE and can serve for better decision making in the concept stage. As is mentioned by Obyn et al. [34], it is better to solve these problems earlier rather than trying to solve them with a huge supply of wood and fuel.

5 RESEARCH QUESTIONS

The umbrella question of this thesis is “how can the humanitarian architectural design methodology be advanced for the better outcome for the people in need?”

In order to answer the big question, the research will answer the following sub-questions:

5.1 SETTLEMENTS

1. How can we analyze settlements?
    a. Compliance with guides and standards
    b. GBV prone areas
    c. Street network quality
2. How can we design better settlements?
    a. Street network
    b. Division of plots
    c. Infrastructure

5.2 SHELTER

3. How can we analyze shelters?
    a. Compliance with guides and standards
    b. Shelter geometry analysis (floor plan and height quality)
    c. Thermal comfort
    d. Identification of parameters’ impact on thermal comfort
4. How can we design better shelters?
    a. Form-finding
    b. Structural analysis
    c. Thermal comfort

6 METHODOLOGY

Overall the research is conducted within two premises: humanitarian architecture and algorithmic computational modelling. Humanitarian architecture is the field where the developed algorithms are applied. It also defines the framework of the overall conduct. Research started with the analysis of the existing guides and methods of planning in humanitarian architecture. Then the important numerical constraints were derived to construct the framework for the research, including emergency settlement and shelter standards.

All of the existing research encountered in the literature review, including the joint work between UNHCR, Stanford University and Ennead Lab [19], used the same GAE for development, which is Grasshopper for Rhino 3D modelling software. Grasshopper is a continuously growing graphical algorithm editing software and platform which is used both for research and practice. The use of it grows day by day. Many side plugins have been developed that address the questions of different disciplines. It also grows links to other software in the AEC for better interoperability. It is not a rigid software whit a defined set of instruments but rather a platform where you can make your own instruments. The research presented in this thesis utilises many of the existing packages. Also, many of the components are developed from scratch.

6.1 LABOUR DIVISION METHOD

The method of design in humanitarian architecture is still through traditional CAD. It means that both the design decision and execution is made by the operator. This thesis proposes that a semi-automated workflow can be used for better and faster work. How does this happen? All of the operations that are required for the final product are divided into two groups.

The first group is the one where human input is critical, like establishing the standards that the design should follow or designing the overall scheme of the settlement or shelter.

The second group includes operations that can be automated, such as the division of the land into shelter plots, form-finding or checking compliance to certain standards.

6.2 SEMI-AUTOMATED DESIGN OF SETTLEMENTS

Here again, the labour division takes place. The planner defines the boundary and principal roads of the settlement. Then by reading the standards defined by the planner, the algorithm proceeds to determine the available area for shelter allocation, shelter positions and so on.

In several cases, both the street network and the collection of shelters are described as graphs. Various graph traversal algorithms are applied to analyse the graph network of streets and shelters.

6.3 SEMI-AUTOMATED DESIGN OF SHELTERS

The algorithms separate the processes of design and visual programming, leaving the first part to the designer and automating the second one. What designers draw is considered a static schema of the structural system, which is translated into the simulation model and drawn in a real-time manner in the same 3D environment. The algorithm is developed in the Grasshopper visual programming environment, where it acts as a backend design engine. Meanwhile, the architect uses the Rhino user interface enhanced with the commands related to the specific task of drawing a shelter.

The following packages are utilized here:

- Kangaroo 2 (K2)- form relaxation [37]
- K2Engineering – structural analysis of large deformation objects. Works with the K2 solver
- Human/EleFront – data transfer from Rhino3D to Grasshopper
- Python and C# scripting

It is worth describing how Kangaroo 2 works since it is the main engine utilised. The designed geometry is represented by a set of particles. The set of goals is applied to determine where each one of those particles should move. For example, if a collection of points describe the geometry of a rod, it means that the points should try to keep the distances between them and to keep the angles between the subsequent segments close to 0° (or any other given value). The strength of the goals is also controlled.

The architect is responsible for designing the shelter, finetuning the relative strengths of individual elements, defining boundary conditions, cutting pattern dimensioning and adjusting the design environment within the provided bounds, like changing precision. On the other hand, the algorithm takes the designed scheme, categorises the elements based on their structural types, solves the intersection events of the topology, reads the strength values, simulates the geometry behaviour and analyses the output model to give feedback about the design performance. The form-found geometry is then fed to the K2Engineering solver to determine the exact structural behaviour. Here the real stiffness values are supplied by the designer.

As part of the implementation of the tool to humanitarian architecture, the algorithm has integrated several UNHCR shelter design standards to evaluate the compliance of the design to those standards.

The algorithm is thought to minimize the necessary input so that the designer can focus on the creation process.

6.4 PARAMETRIC MODELS OF SHELTERS FOR THERMAL ANALYSIS

A different approach is used for modelling the shelters for thermal analysis. Here the entire model is created generatively. No geometry input from an architect is required. The reason is that all the inputs should be parametric in order to make the automated analysis for various solutions.

Computer-aided design technologies now have been developed to an extent where now they are an indispensable part of research in the AEC industry. As such, the design, modelling and assessment of emergency shelters can be considered to be a part of this industry within the domain of humanitarian architecture. So far, the computational modelling of emergency shelters has been mostly performed by means of traditional CAD. There have been relatively few attempts to model small humanitarian units such as tents and emergency hospitals within a BIM environment since they do not contain a massive amount of information and information-driven conventional construction elements. Aside from the computational modelling, the processes of environmental energy use assessment will be examined, and new methods suggested for a better and faster outcome. Several practices of modelling the virtual emergency tent model in a simulation environment and the later comparison of the obtained results with the actual tests show that these models can be highly calibrated and can accurately portray how an emergency unit will thermally behave in a given condition. Figure 14 shows the workflow diagram.

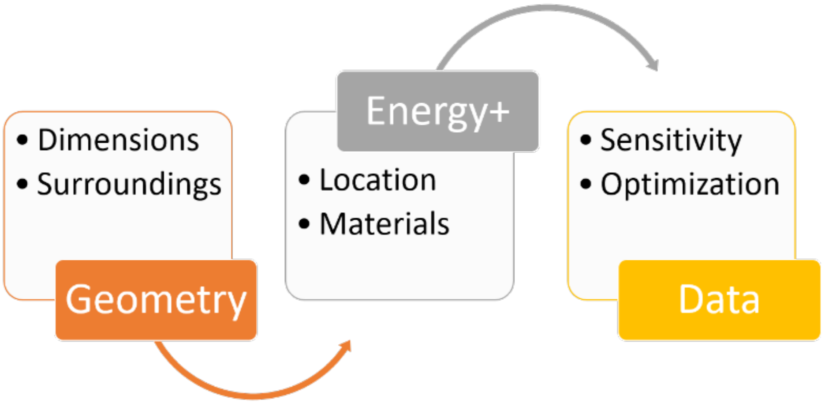


Figure 14 Workflow diagram

6.4.1 Geometrical model

Traditional CAD tools let us precisely model an instance of a physical unit within a computer environment; however, these models are static, and any design change or slight modification of parameters will require partial or full remodelling of the virtual object.

In contrast, the recently developed algorithmic modelling tools offer the possibility to create not just a single instance of the architectural unit but instead the algorithmic definition of the unit, which requires parameters as input (dimensions, topology etc.). These relatively new methods have been proved to bring advancements in the AEC industry but the humanitarian architecture and emergency tent modelling, in particular, seem to have not adopted to wide use these tools and methods.

As part of this study, several widespread emergency units have been taken for geometrical and later thermal analysis. The chosen emergency tent units are:

- UNHCR family tent
- IFRC Finland tent
- Bettershelter
- UNHCR geodesic tent
- Textiles Hub - T2 multipurpose unit

The parametric definitions of emergency tents are created, and each of these tents has several degrees of geometry control. The change in any of the parameters leads to instant remodelling of the unit (Figure 15 and Figure 16).

The control parameters are given in the appendix (13.4, page - 150 -).

The parametric definitions are created via visual programming. Most of the modelling is performed by Grasshopper's native components.

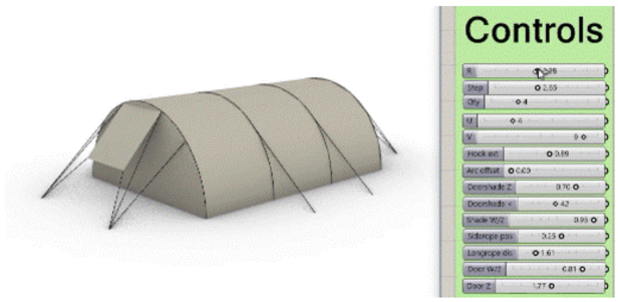


Figure 15 IFRC Finland tent parametric model

Figure 16 Other parametric models of tents

In order to process large quantities of simulations in an automated manner, the Colibri package is used.

6.4.2 Thermal Model

As we see from the literature review, Energy+ has shown to be a valid tool for the assessment of emergency shelters' thermal comfort. However, so far, these assessments have been done by manual modelling. With the recent advancements of the Grasshopper platform, Energy+ thermal simulation procedures can now be integrated within the parametric definition by the open-source code from LadybugTools. This study intends to extend the parametric definitions of emergency tents and also involves the thermal analysis parameters in the same dynamic fashion, so we will be able to leverage the inputs. For this purpose, the definitions of the UNHCR Family tent and Textiles Hub's T2 multipurpose tent have been chosen for further development.

SECTION 1: SETTLEMENT

7 SECTION 1 – SETTLEMENT

7.1 INTRODUCTION TO SECTION

This section will demonstrate the results of this research at the settlement scale. The first chapter presents tools and methodology to automate or semi-automate the emergency settlement design and evaluation, including WASH facilities and fire safety. Several recursive land subdivisions into shelter plots algorithms are also demonstrated. It will also show how such methods can be implemented into a web interface.

The second chapter presents a case study where an existing abandoned vernacular settlement was assessed for suitability to turn into an emergency settlement. This chapter also presents an automated methodology to find the optimal places for the allocation of water distribution tanks. The procedures include analysis of the road network end vehicle accessibility. Fire safety is also addressed.

The third chapter will show the estimation of gender-based violence risk. A framework will be developed to help the side planners to address this issue in the design process.

7.2 ALGORITHMIC PLANNING AND ASSESSMENT OF REFUGEE CAMPS

7.2.1 SITE SELECTION

There have been few attempts to create tools that may automate camp planning to some extent. From these attempts, probably the most well-known and freely available tool is the UNHCR's site planning app (Figure 17). As appealing to the actual site planner this app may sound, it is a mere calculator that uses simple formulas to solve how many square meters you need for a certain amount of people and other problems alike. With no intention to devalue the importance of such apps in the hands of the planners, it must be addressed, however, that this app does not in any way give clues about the spatial configuration and placement of the camp. In this regard, the algorithm presented in this chapter is the extended version of this app that, aside from having implemented similar calculation functions for key metrics, also provides a crucial understanding of the site's spatial arrangement and limitations.

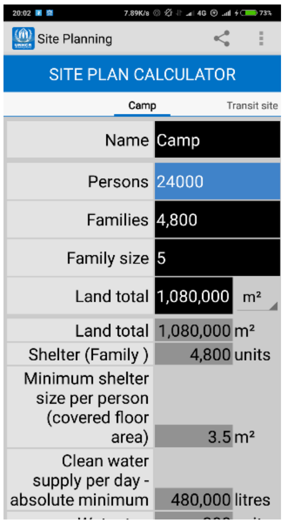


Figure 17 UNHCR site planning app

Before planning the actual refugee camp, a site selection has to be done. As it happens in reality, there may not be much freedom in choosing an optimal location in a country. The location is often determined by the local governments; however, there can be decision freedom for the specific placement within the area designated by the government. Here some consideration plays a role. UNHCR provides guidance on how to choose a good location for a camp. These guidances include:

- Optimal terrain gradient for the camp
- Recommendation to avoid flood-prone zones

Given the terrain (Figure 18 A), the following procedures are developed that can help to find the optimal placement of the camp.

At first, the terrain gradient is analysed. UNHCR's norms on a gradient are used in this case to find out optimal regions where the land has a limited slope but is not flat either (Figure 18 B, suitable areas are covered in green).

The second key consideration is flooding. According to the established guidelines, it is advised not to place a refugee camp in flood-prone places. In order to address this concern, a rainfall simulation is performed on the terrain to find the places where a large amount of water may accumulate. These zones are delineated in blue (Figure 18, C).

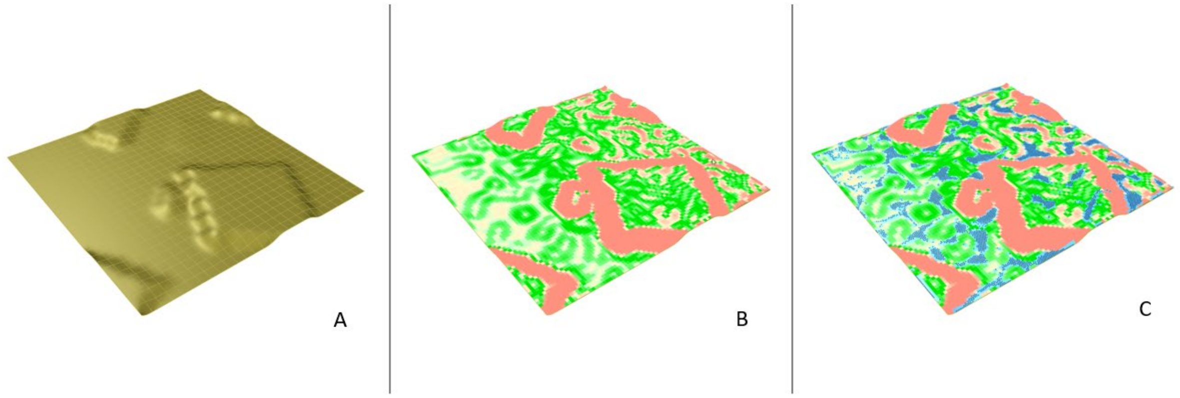


Figure 18 Terrain analysis

After the two analyses are performed, an understanding of where the camp can or cannot be located emerges. In the next step, the area per people logic comes into play. Like in the UNHCR site planning app, based on the supplied number of people, the required camp area is calculated. In this case, however, the area is not just a number but rather is used to outline the camp itself. When a site planner picks a location for camp placement, a growth algorithm starts to grow the outline of the camp avoiding the flood zones and suboptimal terrain until the grown area is sufficient to house the designated amount of people. Once the proper placement is found, a subdivision algorithm (discussed in detail in 7.2.4 page - 58 -) is used to divide the land. Here the UNHCR's division hierarchy is used as shown in Table 2.

Table 2 Indicative modular planning units

Module	Structure	Approximate number
Family	1 x family	4 - 6 persons
Community	16 x families	80 persons
Block	16 x communities	1,250 persons
Sector	4 x blocks	5,000 persons
Settlement	4 x sectors	20,000 persons

The divided land is then populated with shelters in community land perimeters (Figure 19). This approach is performed manually in many camps. The design here is a heuristic solution that can be used by site planners as a general principle on how the camp can be in the given particular context. In the circumstances where people's livelihoods are at stake while the plans of the camp are being laid out, every day saved in planning is a day gained in living for refugees. The quick planning algorithm presented here can decrease the planning time significantly.

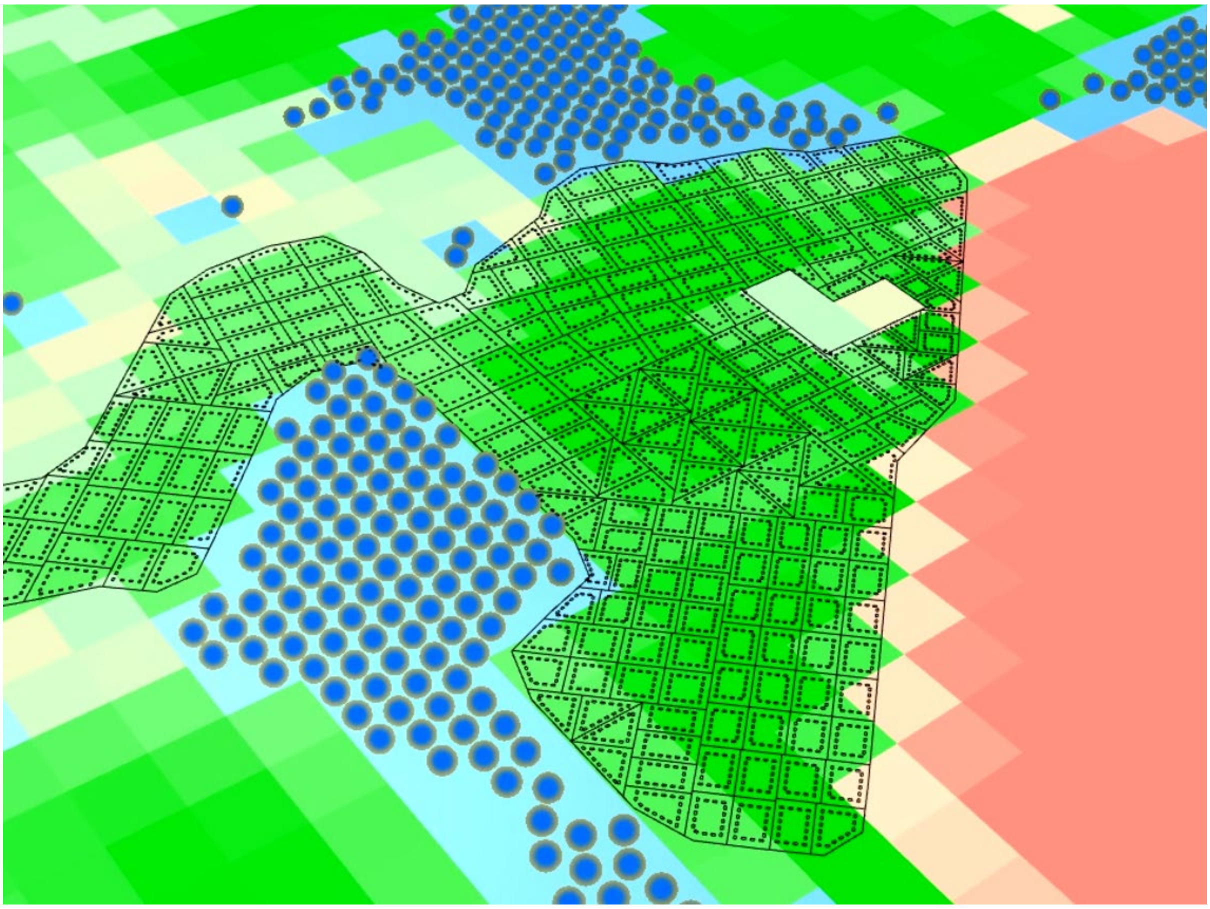


Figure 19 Automatic camp generation

7.2.2 Boundary creation method

The generative design process of planning a refugee camp starts with the planner input of the curves that represent the boundary of the to be camp layout and the road network. Once those are placed, the algorithm detects the areas that lie between those curves taking into consideration the widths of the roads. As a result of this phase, we obtain the boundaries of the regions that can be populated with shelter plots Figure 20.

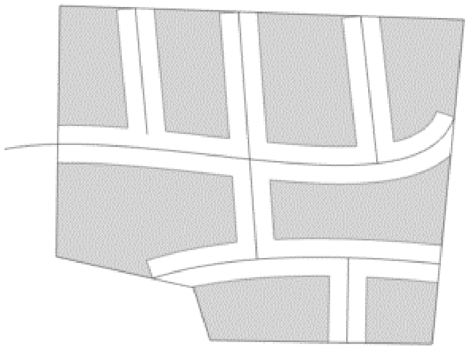


Figure 20 Defining suitable regions

Later the algorithm recreates an oriented bounding rectangle of those regions. The untrimmed boundaries are subdivided into plots with numerically controlled parameters such as the area per person standard by UNHCR Figure 21.

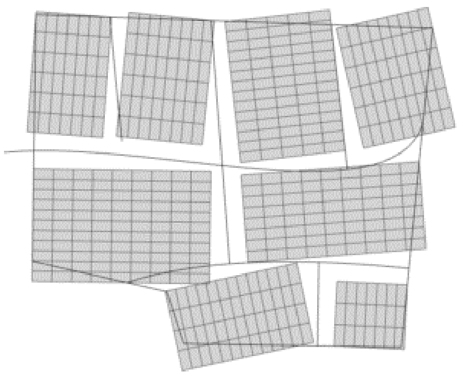


Figure 21 Subdividing untrimmed regions

As a result, some of the plots may be out of the defined boundary, so the following logic is implemented to determine which ones should be deleted. If the sum of the distances of the corner points to their closest point in the region is greater than a given threshold, then that plot is culled Figure 22.

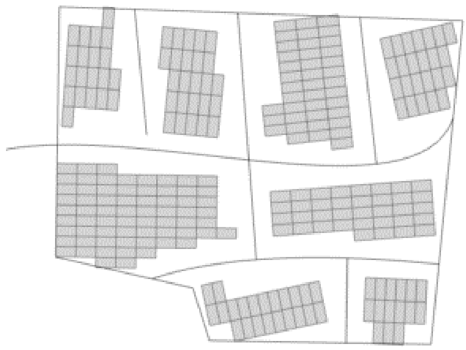


Figure 22 Culling by the threshold

The remaining collection of plots is considered valid. Shelter geometry is generated inside these plots again following the UNHCR standards, and the planner can see the clusters and the quantities of shelters in each cluster Figure 23.

Figure 23 Camp stats

7.2.3 Path creation method

As an alternative to the boundary creation method, a path creation method was developed. In contrast with the former one, here, the input is given only by the roads and the camp is then formed out of the street network (Figure 24).

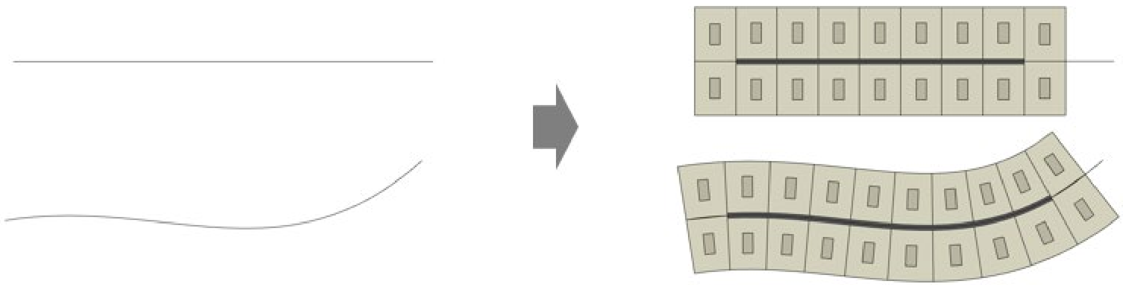


Figure 24 Plots along roads

The road curve serves as the starting point. At first, based on the given standards, the possible amount of shelters are calculated that can fit along the curve. If the curve has an open end, then the end caps are filled with shelter plots in a way that the middle road starts and ends inside the plot distribution.

If the plots overlap, then the intersection lines are used to determine the new boundaries for the plots. The adjusted new boundaries are compromise solutions between the conflicting shelter plots (Figure 25).

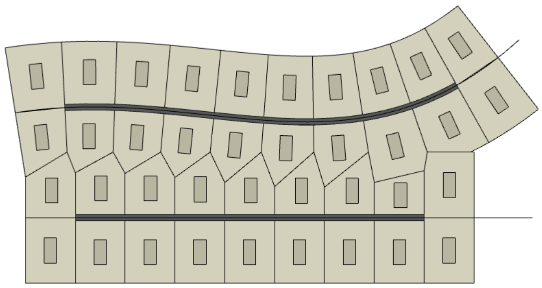


Figure 25 Plotting overlap

In the crossroads, two separate groups of shelter plots overlap each other. In this case, the overlapping ones are separated to form a common area. The common area is later on considered as small tasks of boundary division problem where a recursive division method is used (Figure 26). This method will be described in the next chapter.

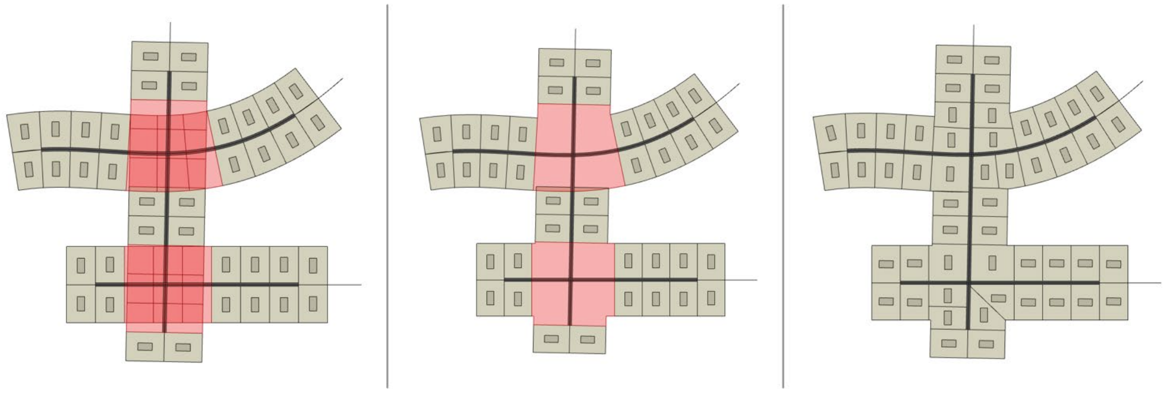


Figure 26 Processing of crossroads

The path creation method described above is fundamentally different from other methods. Still, it allows the implementation of refugee camp planning standards into an automated workflow.

7.2.4 Recursive division method

7.2.4.1 INTRODUCTION

When it comes to the land allocation for refugee camps, availability is often an issue. There are many stakeholder interests at stake, which leads to limited sizes of camps. On the other hand, over time, the population living in the camp may exceed the initially planned quantities, which in its turn may lead to over densification of the camp. In this regard, the optimal use of the available land is paramount. When it comes to the division of the camp land into individual shelter plots, as we also saw in the boundary division method, a grid layout is often used. Aside from some advantages, the grids also have several disadvantages as well, including but not limited to the following:

- Family plots have similar areas for everyone regardless of the family sizes
- Most of the time, the camp area may not be fully populated by plots, so in some places, vacant places emerge, which eventually may be populated by unplanned sprawl

Ergo, a new planning methodology is necessary that can overcome the grid layout disadvantages whilst maintaining the possibility to yield individual plots that are suitable for hosting families.

7.2.4.2 DIVISION ALGORITHM

The division of the area is done by taking an area of land and recursively dividing it into two pieces as long as the resulting plots are within the area threshold. The divisor is a line segment that is determined through several different methods. The pseudocodes for these methods describing the process in detail are given in the appendix (13.2 page - 146 -).

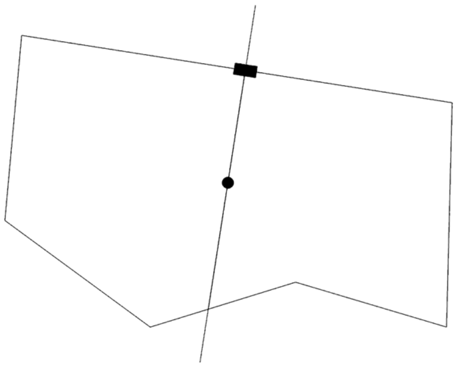
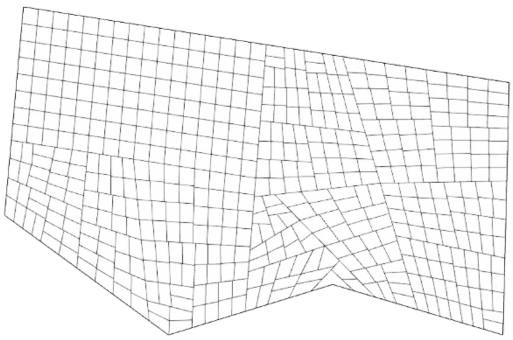
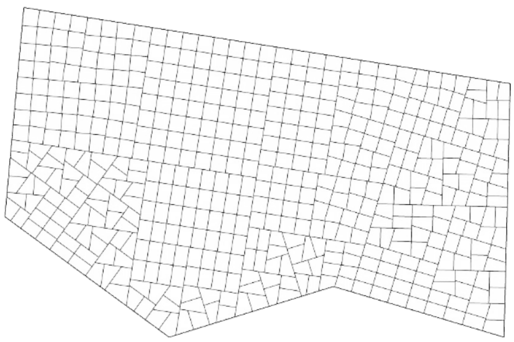
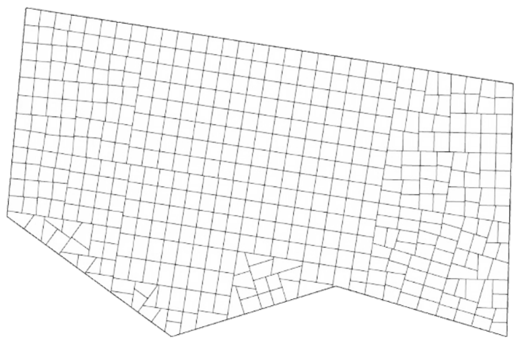
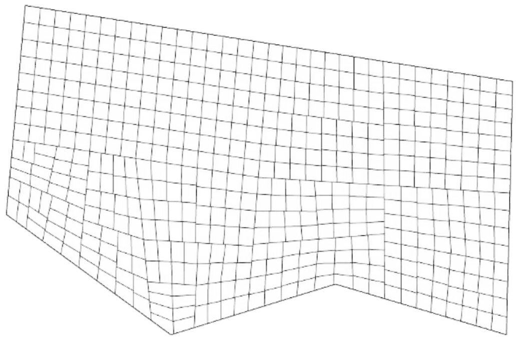


Figure 27 An example of a divisor

After the recursive division based on the chosen method, different layouts will emerge. Interestingly, in some of these layouts, the potential roads instantly emerge.

Table 3 Resulting layouts of the divided land

Method 1: Area centre to closest edge's midpoint division	Method 2: Area centre to the closest point on boundary division
	

Method 3: Longest side midpoint perpendicular division	Method 4: Longest side midpoint to area centre division
	

Here are some considerations about the quality of the output. The resulting layout always uses 100% of the available area. Nearly all of the resulting plots have such shapes that allow the placement of the shelter. Concave shapes are very rare. The sizes vary. Although in some cases, there may be some occurrences of grid-like patterns, the plots are not standardised. When it comes to distributing the plots to the families, twofold argumentations may arise in regards to the preference of this method over the grid one. On the one hand, this method provides various sizes such that bigger families can get bigger plots. On the other hand, equal-sized families may receive plots with negligible differences in size. In order to address this, an automated family allocation algorithm was developed that can match the collection of families to the collection of the plots finding the best pairs. For now, only the area per person requirement is taken into account; however, following the same logic, more complex matching functions can be constructed that also take into account things such as the presence of a disabled person in the family, parental composition etc.

7.2.4.3 FAMILY ALLOCATION

In the given example, a hypothetical camp was made, where the task was to allocate families given in in the drawn camp (Figure 28).

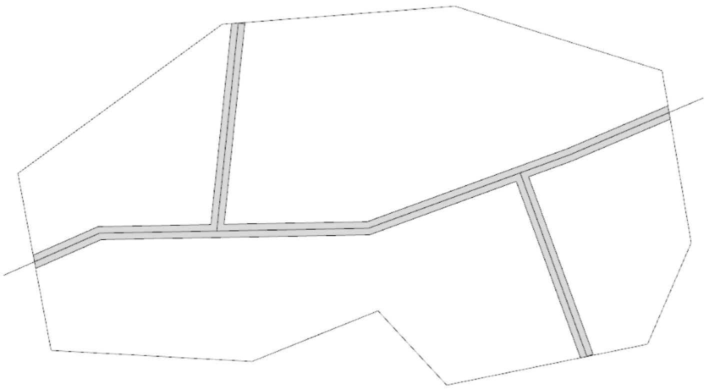


Figure 28 Hypothetical camp layout

Table 4 Family composition of a hypothetical camp

Family Size	Plot Area Per Family Size	Shelter Area Per Family Size	Quantities
10	350 m^2	35 m^2	10
8	280 m^2	28 m^2	15
4	140 m^2	14 m^2	28

The Plot and Shelter area requirements are derived from the family sizes using the UNHCR norms. The available land is now divided into smaller plots.

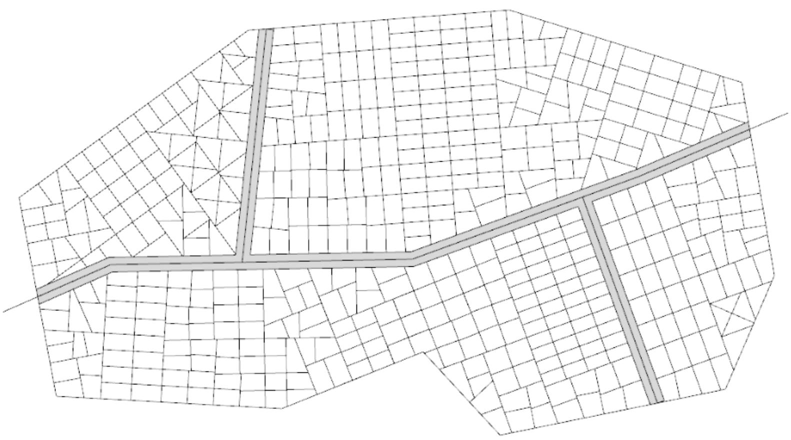


Figure 29 Divided camp

The resulting layout given in Figure 29 shows only the last layer of divisions. During the hierarchical division, the intermediate boundaries are also stored in the collection, which shows the boundaries before they are divided at each step. The reason for storing them is that the required area for families or public venues may vary a lot. By having the collection of recursively divided boundaries, a matching algorithm can be used that finds the best match of the area requirement and the actual area that the boundaries have. After matching a family to a particular parcel (green) from the hierarchy, if the selected parcel has subsequent divisions, they are discarded (red) (Figure 30). Grey parcels are either intermediate stages of the division or the remaining unused ones.

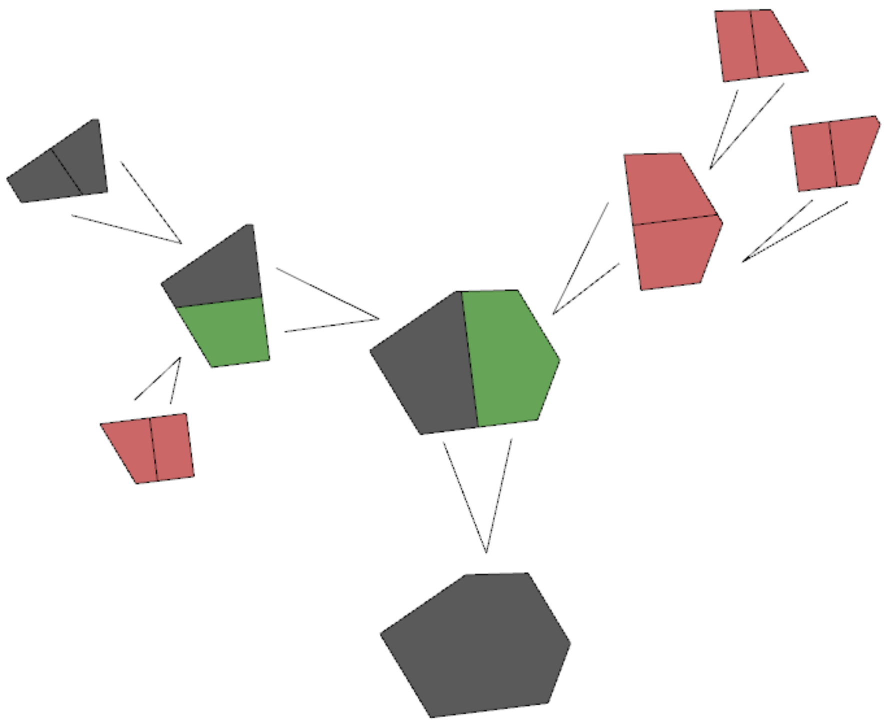


Figure 30 Selection from the hierarchy (Green: Selected, Red: Discarded)

The resulting layout is the camp allocation with matched family-plot pairs. The remaining plots from the last layer of division are maintained as extra capacity to host more families.

Figure 31 shows the distribution of families in the camp, where the bigger families are shown in darker colours.

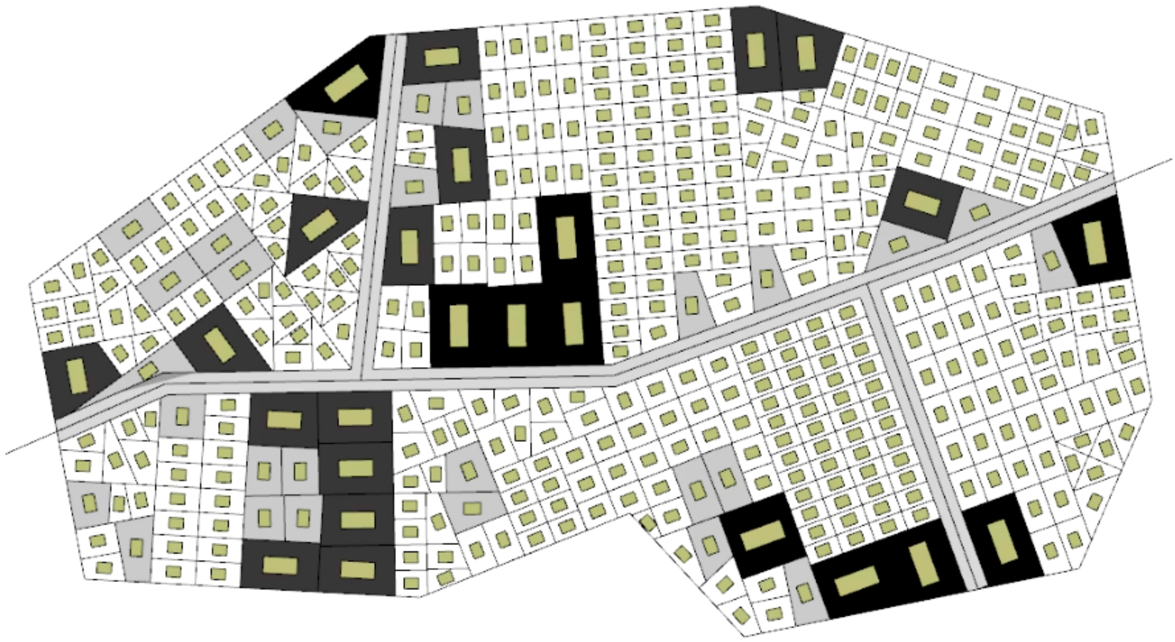


Figure 31 Allocated camp layout

7.2.5 INFRASTRUCTURE

One of the aspects that the site planners should consider in planning refugee camps are the WASH (water, sanitation and hygiene) facilities. The arrangement of those facilities is also guided by the defined standards. The standards include the minimal and maximal distance to the shelters, the number of households per facility etc. Here again, the semi-automated workflow takes place. Once the site planner places a point indicating the position of the WASH facility, the algorithm takes out the shelters that are located very close to that latrine. Also, given the maximum distance that the shelters should be from the nearest WASH facility, the algorithm determines the closest one for each shelter then determines whether the distance to that particular point is greater than the standard or not. If it is greater, the sheltered plot is coloured to give visual feedback to the planner.

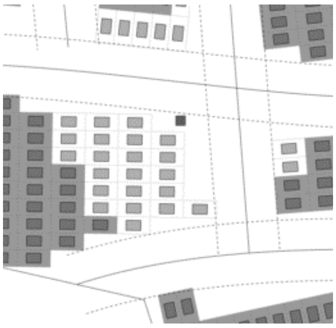


Figure 32 WASH facility reach

7.2.6 GENETIC OPTIMIZATION

Since the process of placing the WASH facilities in an optimized manner would require many design and editing procedures from the planner, several optimization algorithms were set up to aid the planner in giving a heuristic placement that the planner can start working with. The generative algorithm is set up to populate the area with **n**<**m** amount of WASH points where **m** is determined by the area of the camp and serves as the limit number. Both the **n** number and coordinates of those points are numerically controlled and serve as genomes for the genetic optimization algorithm. Having the collection of points and the external point that serves as the hypothetical water distribution point where water can be supplied from a pipe network is constructed following the method described in the appendix (13.3, page - 149 -). The fitness objectives of the optimization algorithm are set as follows:

1. Minimize the number of shelters that are out of reach
2. Minimize the overlap between the effective regions for each WASH point
3. Minimize the total length of the constructed piping

The multi-objective optimization algorithm creates a set of solutions that are optimized and can serve as a base model for the site planner to work with (Figure 33). Overall, several thousand attempts of the design were made (Figure 34). From these attempts, the designer can choose solutions that perform the best on either one of the goals or on average. Several compromise solutions can also be selected through the Pareto Front method.

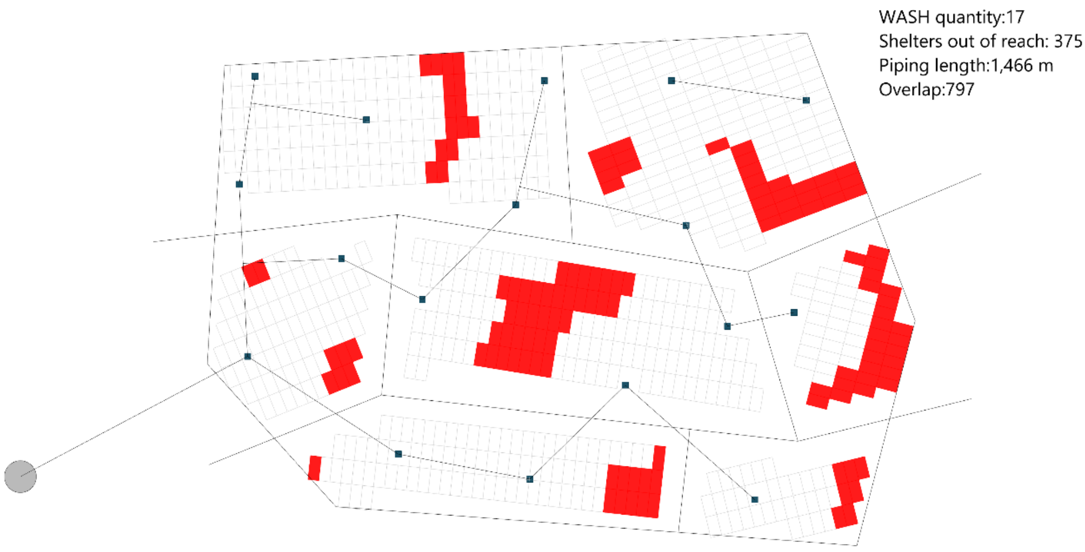


Figure 33 Example of a generated layout of WASH points and piping network

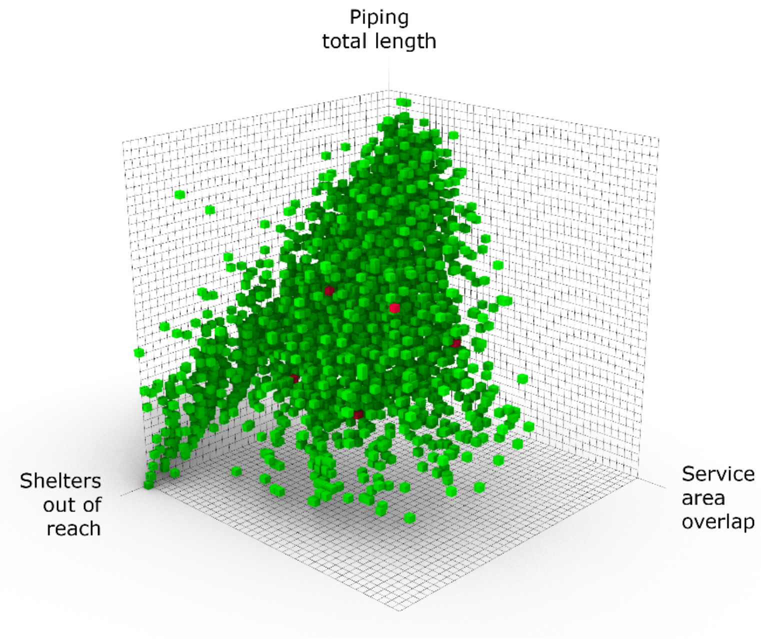


Figure 34 Optimization attempts: each Cartesian axis corresponds to a fitness goal

7.2.7 Fire safety

Researchers show that there has been a dramatic increase in refugee camp fire occurrences in recent decades [38]. It depends a lot on settlement planning [39]. UNHCR defines that there must be a fire break of at least 30 meters wide every 300 meters. The presence of such guidelines is instrumental since many planners can refer to them. However, there is a certain ambiguity about this guideline. Figure 35 shows an example of shelter placement.

For this layout, we can calculate the fire travel distance between the first and the last shelter. One way of doing it would be to take the distance between the two points. Another way would be to create the path of fire propagation. As we can see in the example, one may highly differ from another. In both cases, if the planner is dealing with a settlement with hundreds of shelters, it can be a very time-consuming task to check all potential fire travel paths. This error-prone activity may lead to the poor performance of the settlement.

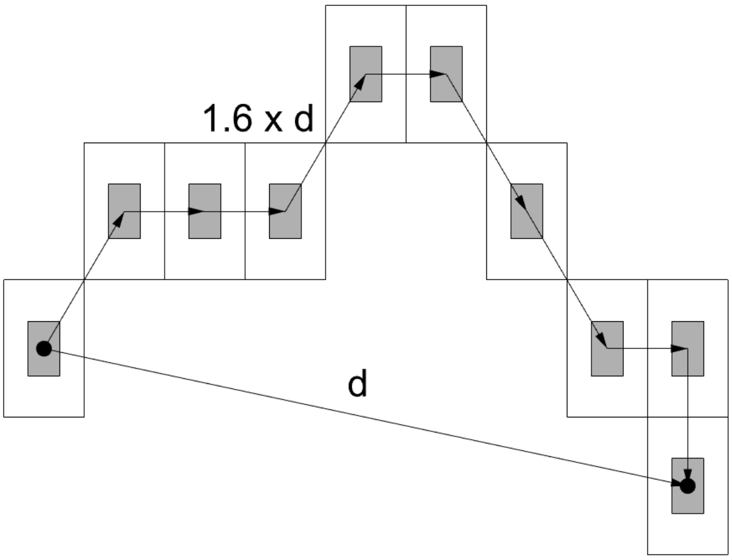


Figure 35 Two methods of fire travel distance measurement

For this planning task, the following algorithm was developed. It starts with the collection of points that represent the placed shelters. Based on their proximity, they are clustered into fire zones (Figure 37). On the computational level, the following logic is implemented to perform the clustering. At first, a Delaunay network of lines is constructed. Then the lines that are longer than a given threshold are culled. The last step results in the emergence of clusters where points are connected to each other with lines only from their cluster, as shown in Figure 36.

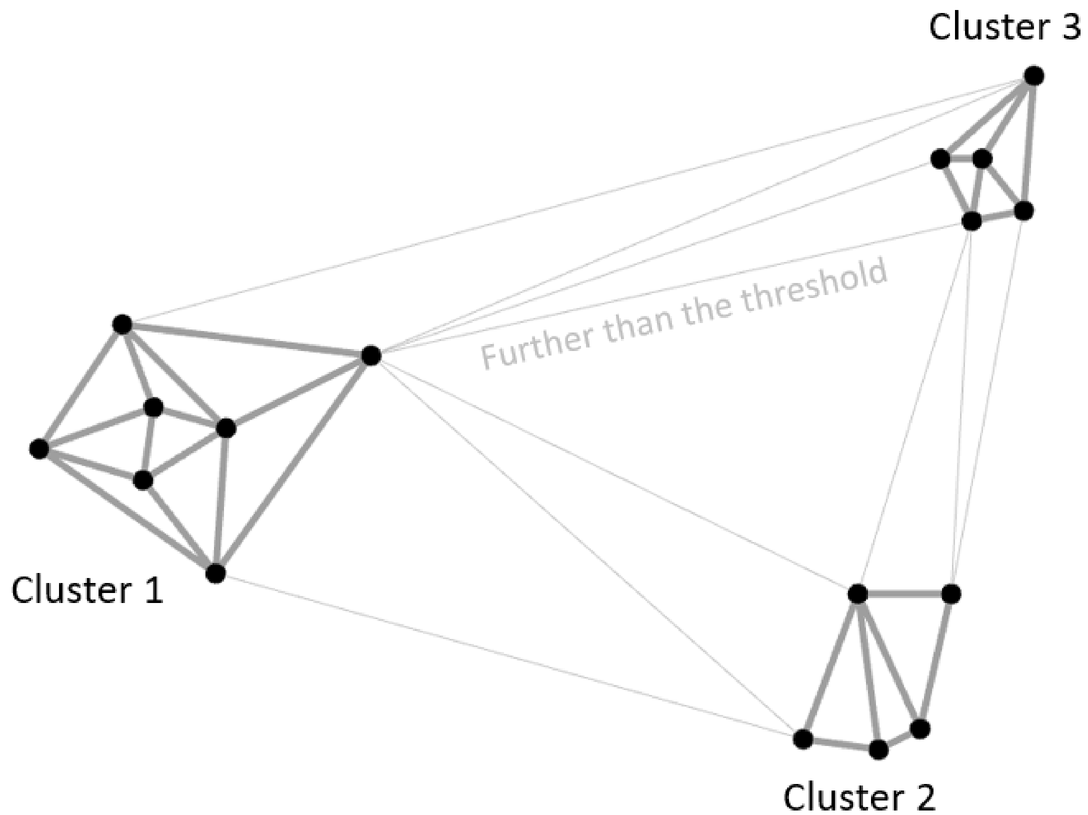


Figure 36 Grouping into clusters based on the fire break distance norm

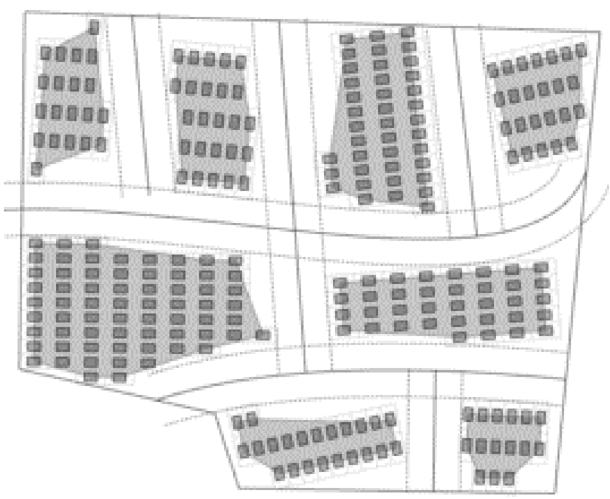


Figure 37 Fire zones

Usually, the separation will occur with the placements of roads. The assumption is that if a fire starts in the shelter of a particular fire zone, it cannot spread to other zones. Then for each fire zone, all possible pairs of shelters are separated. With the points of shelters and fire spread lines, a graph network is created (Figure 38).

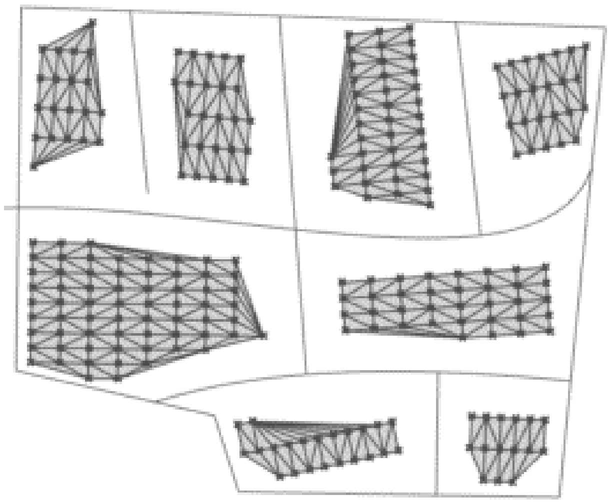


Figure 38 Fire propagation lines

Then using a graph traversal algorithm, the shortest travel distances are found between each pair. If the found fire travel path is longer than the given value (300 m in this case), the path is visualised (Figure 39). This instant feedback helps the planner to identify the fire risks and to act accordingly.

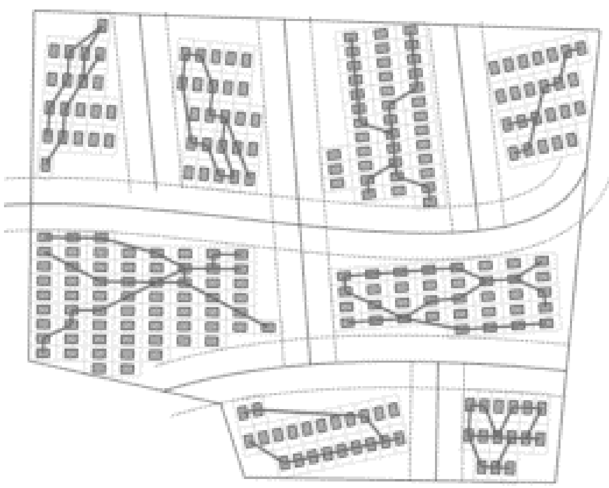


Figure 39 Longest samples of shortest walk routes

7.2.8 WEB APPLICATION

As normally happens in the emergency response, the solutions must be low tech in a way that anybody should be able to use it. In this regard, the research presented in this chapter utilises computational modelling software and algorithms that not many field site planners are able to use. However, in its essence, the problem can be narrowed down to a simple set of inputs that the user needs to supply and the outputs that are needed. To streamline this process, we built a test web user interface (Figure 40) of the presented algorithms using Giraffe.

Giraffe is a web application that allows Grasshopper scripts to be deployed online via an intuitive interface. This allows non-experts to utilize the script to solve problems without specialist training or software licenses.

This technology is highly relevant for refugee camps enabling them to be designed quickly and with detailed automated analysis ensuring maximal safety for occupants.

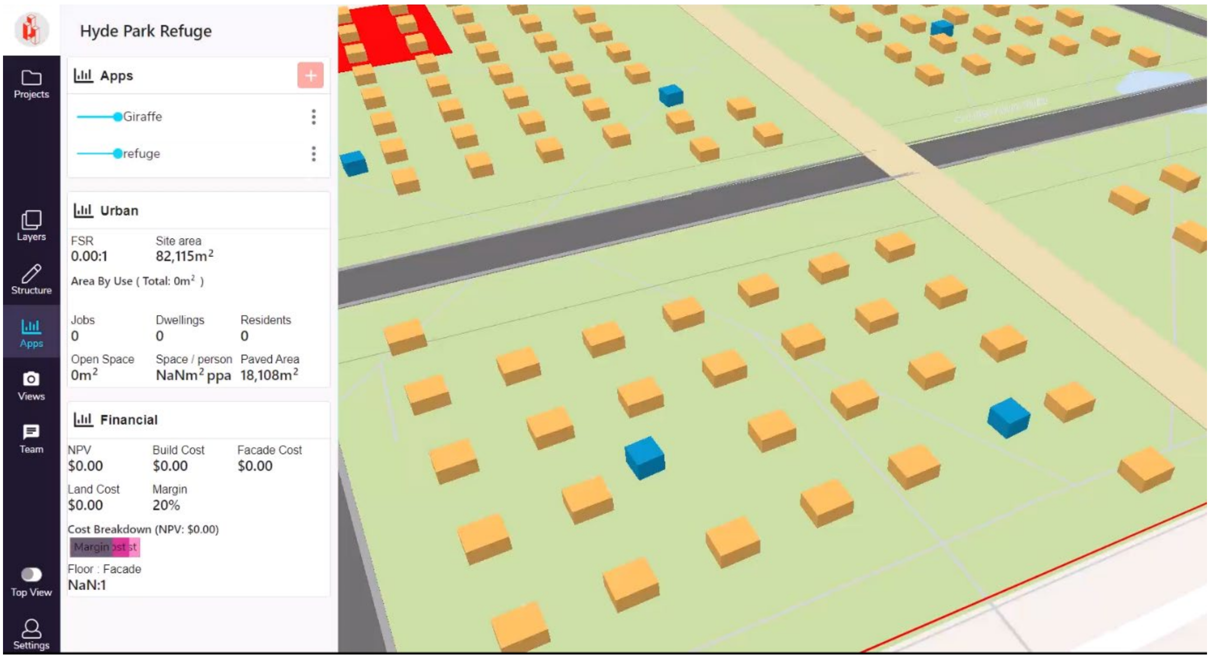


Figure 40 Camp planning web interface

7.3 CASE STUDY 1 - ANALYSIS OF EXISTING REFUGEE CAMPS. ZAATARI

Figure 41 Zaatari camp (photo credit Samsamwater)

By using the above-demonstrated toolset, existing emergency settlements can also be analysed. As the first case study, the Zaatari refugee camp (Figure 41) was selected. Open source OSM data is available for this camp. Figure 42 shows the available data. It includes:

- Road network
- Zone division
- Several public facilities (sports, school etc.)
- Locations of WASH facilities

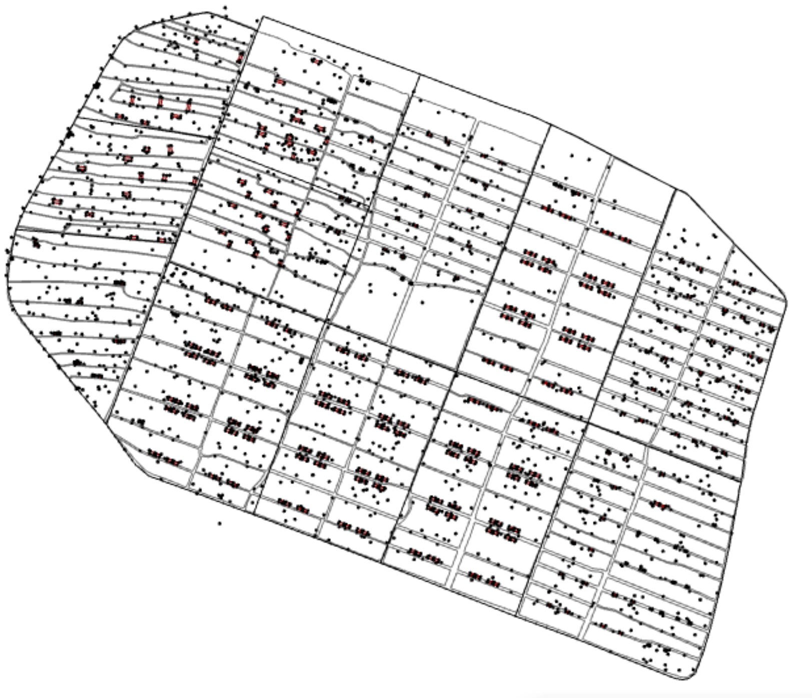


Figure 42 Existing OSM data

However, the exact locations of shelters were not available. A uniform distribution was placed in the available regions to serve as a proxy for actual shelters. By using these proxy locations, the distance to the nearest wash facility for each shelter was calculated. Then the distances were compared to a UNHCR norm, which is 50 meters. By using the allocated information about the distances to the closest facility, a colour-coded map was created to show the shelters that do not have a WASH facility close enough to them (Figure 43). An estimated 7% is not compliant with the UNHCR norm. This study is not precise since both the available OSM data and the distribution of shelters are not accurate. However, it proves to be working, and if given better data, it will show reliable analysis.

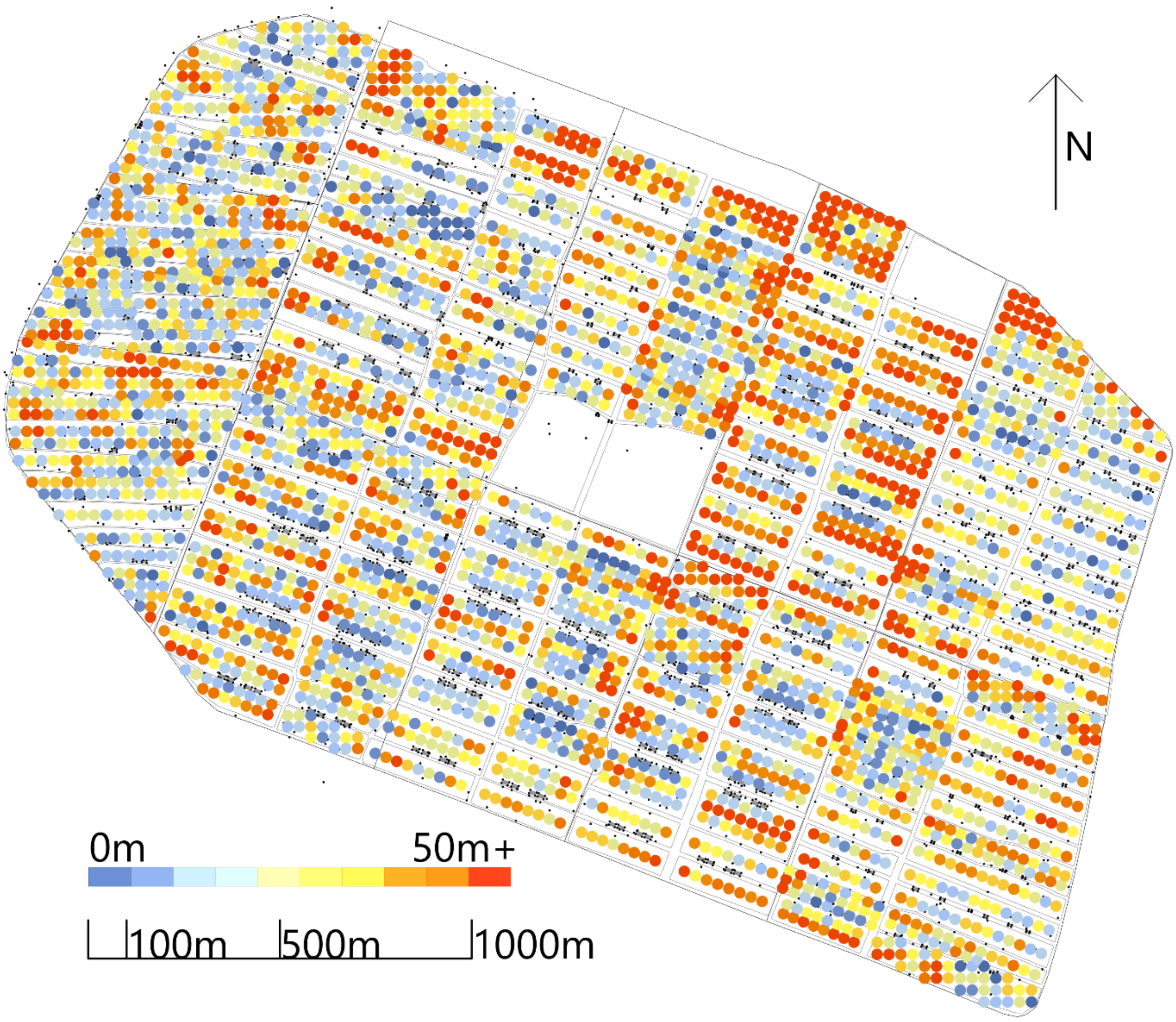


Figure 43 Latrine reach analysis

Another issue is fire safety. following the UNHCR norm of 300 meters maximum distance for fire propagation, the algorithm analyses all potential fire spread paths through the construction of a connectivity graph and the resulting traversal paths between all pairs of shelters within each cluster. Whenever it catches a case where the fire may travel more than 300 meters, it highlights the path between the origin and destination. As we can see in, there are several regions that are not compliant.

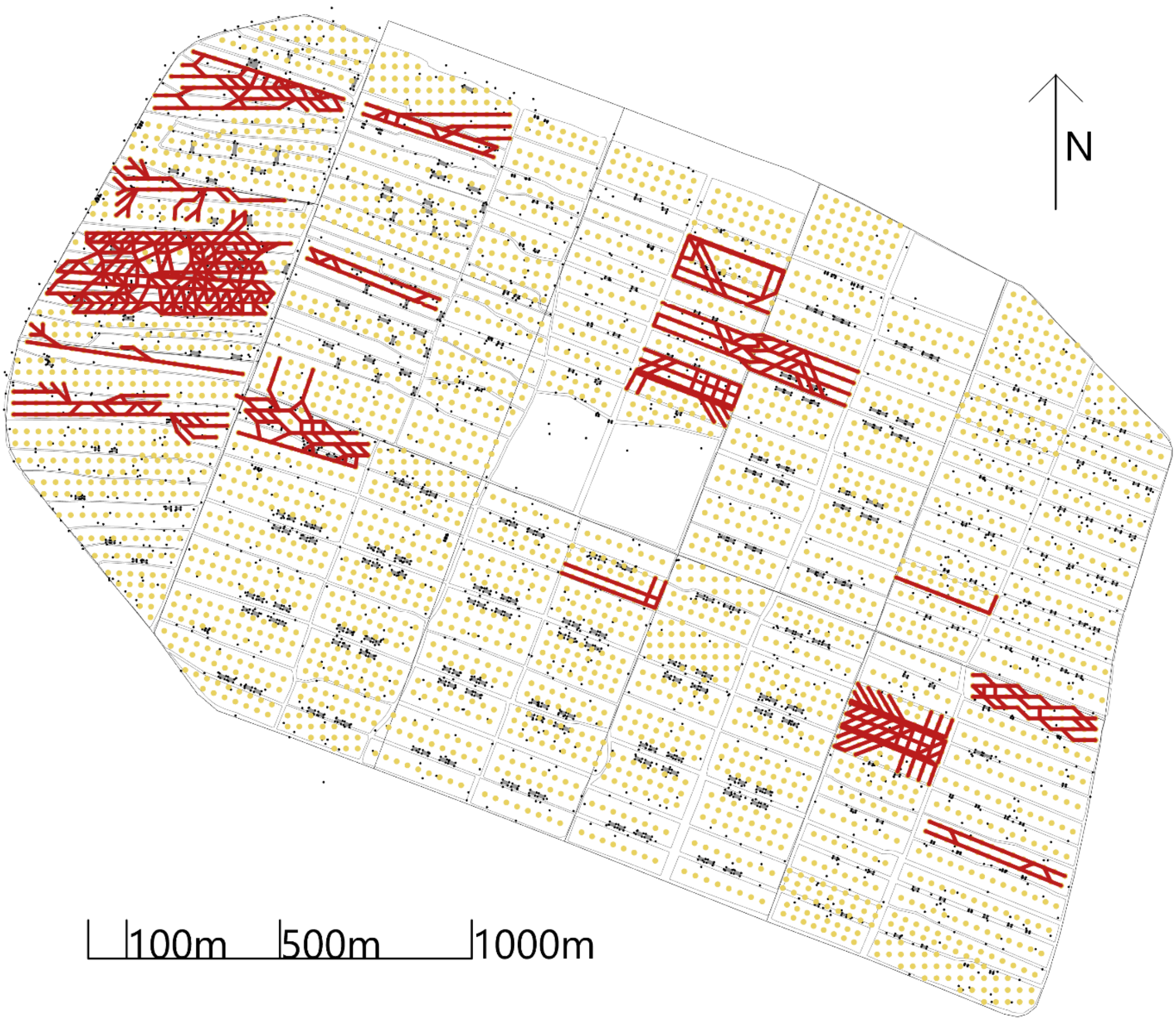


Figure 44 Fire propagation lines

The demonstrated methods can be applied to any existing refugee camp for evaluation. The more data is available; the more detailed and accurate the results will be. The norms given by UNHCR for distances refer to linear distances. However, if the street network is available, in a similar fashion with graph algorithm for fire safety above, the actual walking distances to the units (WASH, garbage disposal etc.) can also be implemented. This will allow us to more accurately predict the distances that people will travel and thus make more informed decisions. In the case of fire safety, road network data is not even necessary. Since the fire break points are not governed by the presence of the roads but rather the fact of whether fire may actually jump to the next building or not, as shown in 7.2.7.

7.4 CASE STUDY 2 - UNDERSTANDING THE DENSITIES AND SHELTER PLACEMENT IN CAMPS: THE CASE STUDY OF AL-HOL REFUGEE CAMP

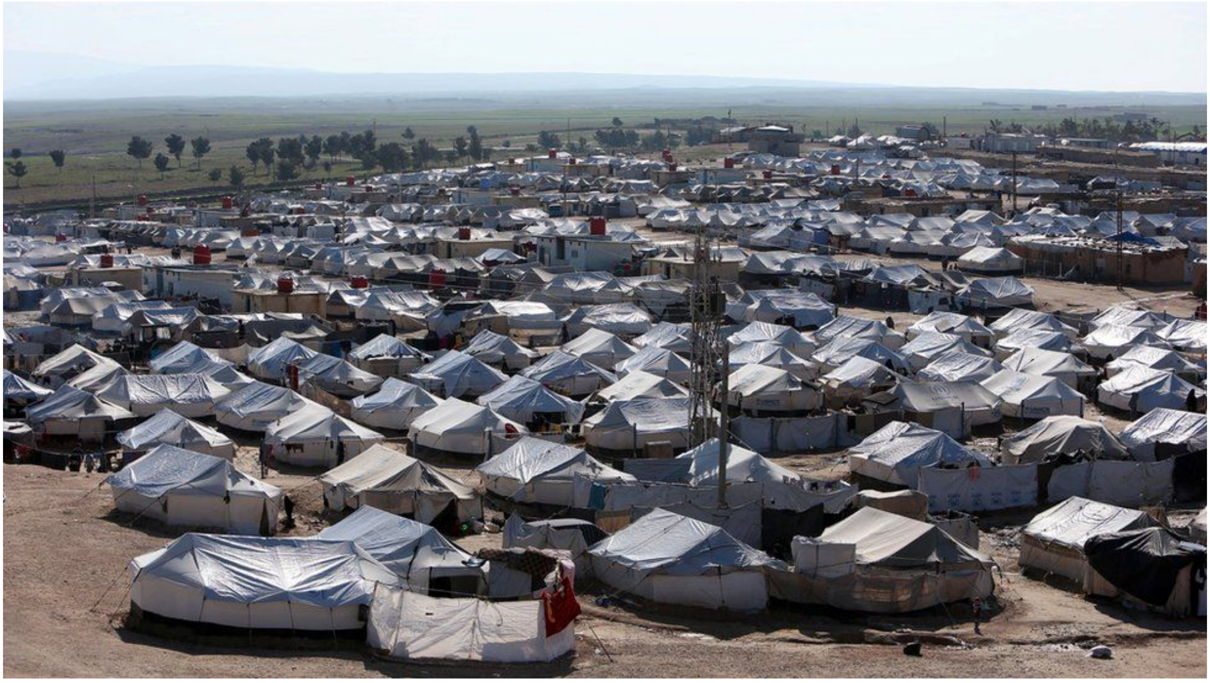


Figure 45 Al-Hol refugee camp (photo from BBC)

Al-Hol (also known as Al-Hawl) camp in Syria (Figure 45) is one of the widely discussed and problematic camps that exist today. It mostly houses the families of ISIS members. The population of the camp multiplied almost eight times in the course of one year. This rapid growth resulted in a camp that had very dire living conditions. One of the biggest issues there is the high density. In cases where there is also a conflict between different people inside one camp, the densified living exacerbates the conditions significantly.

The algorithmic potential presented in this thesis can not only be used to design new camps but to gain important insights about the existing camps as well. Luckily the current layout of the Al-Hol camp with the placement of shelters is available in the OSM (Figure 46).

Figure 46 Al-Hol refugee camp from OSM

One of the key metrics of the refugee camp is its density. Despite its importance, there is a lack of methodology and tools for the thorough analysis of densities in refugee camps. The most common metric used is the area divided by the number of people, which gives a single overarching value for the camp density. However, the refugee camps, in that sense, are a lot like cities, where they can have various districts that are different from one another, particularly by their densities. In this regard, even if the single number describing the camp density suggests that the camp is a good camp, it may not be the case. The single density value is the average of the entire site. What is more important is to understand the distribution of densities across the entire settlement. The same average density may have different distributions, hence different qualities of life.

So in order to gain a deeper understanding of the camps, a subdivision has to be done. Here two different methods were tried that are elaborated below.

7.4.1 Method 1: Division by shelter proximity clustering.

For this method, at first, the clustering methodology presented in 7.2.7 is used. Suppose we take the facilities that define the camp population density that would be the places where they actually live. So this division system is based solely on the existing allocation of shelters. We can think of shelters as points scattered in space with varying proximity. In places where two shelters are close enough, they may be considered to be belonging to the same spatial cluster. In such logic, several shelters can come together to form a cluster. When there is no other shelter within the given proximity threshold to any of the shelters in one group, then we can define that as one separate cluster of shelters.

With this method, the entire camp can be divided into smaller groups of shelters. Later on, the convex area of the clusters is estimated. Here, once the representative area is determined, the density is estimated for every cluster. The gathered densities now can be compared to the established norms and guidelines for assessment.

By applying the above-articulated density measurement logic, the detailed density map of the Al-Hol camp was derived (Figure 47). It is evident now that certain (red) clusters are more densely populated than others and are not complacent to UNHCR norms.

Figure 47 Shelter cluster density distribution of Al-Hol camp

7.4.2 Method 2: Density grid

This method is more straightforward and does not take into account the internal spatial structure of the settlement. The estimation of the density distribution across the camp is achieved by superimposing a measurement grid on top of the camp layout. The shelters falling into each cell are identified. Then the density is estimated for each cell, altogether portraying the density distribution for the entire camp (Figure 48).

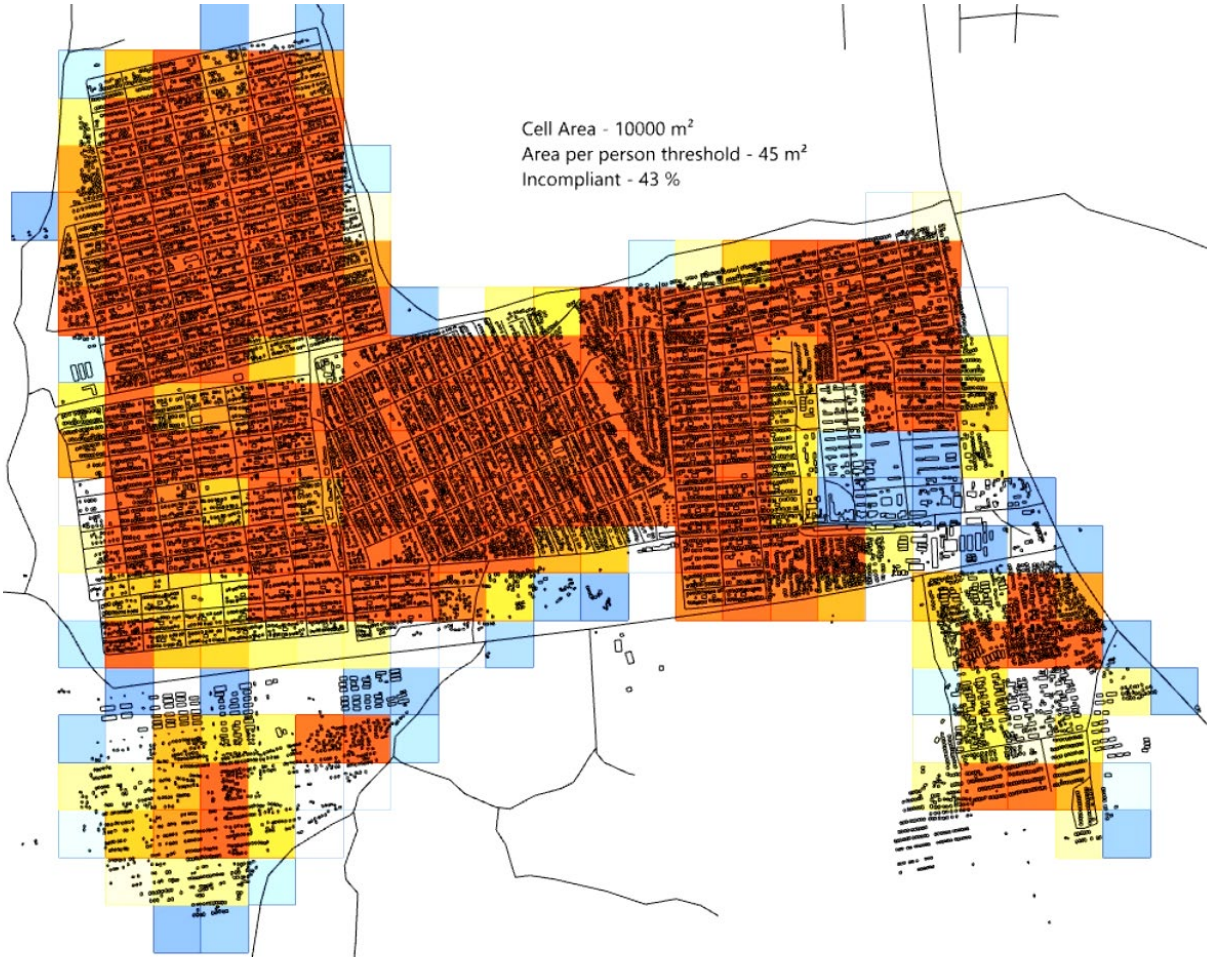


Figure 48 Density distribution by grid measurement of Al-Hol camp

Both of the assessments in this case study were made by the assumption that an equal amount of people live in each shelter. This is never the case; in reality, however, these two algorithms can be easily coupled with the census information of the camp and yield reliable information. The gathered insights about the density distributions can be used by the authorities that operate the camps in order to make interventions where needed. Timely effective actions can reduce the risk of internal conflicts virus spread and improve the livelihoods. These algorithms can also be used as monitoring tools to track densities over time.

7.5 CASE STUDY 3 - ASSESSMENT OF GBV (GENDER-BASED VIOLENCE) RISK THROUGH THE URBAN STRUCTURE OF THE SETTLEMENT

UNHCR has published several guides on how the refugee camps should be planned. As gender-based violence is a major issue in such settlements, there has also been a work dedicated to understanding the planning principles that affect the occurrence of GBVs therein. A notable contribution to the body of knowledge in this domain is the publication of a site planning guidebook named “Guidance to Reduce the Risk of Gender-Based Violence” by Jim Kennedy [40] as part of the IOM and Global Shelter Cluster joint effort.

While the guidebook conveys a very important understanding of how the GBV works in camps and how the settlements should be planned in order to minimise the risk, it does not provide detailed technical guidance on how to implement these planning principles practically. In other words, there is a well-formulated theoretical understanding but no developed tools of implementation.

The developments shown in this chapter are the practical application of some of the key concepts described in this guidebook.

The aim was to develop an algorithm that could make an estimation of the GBV risk for different parts of the road network. The main guiding principle taken from the guidebook was the following. If the road is not well observed by people and it is long, then there is a high risk of GBV there. There is some ambiguity about what “well-observed” or “long” mean.

Firstly, let us establish what the metrics of street observation are.

The first assumption would be that most GBV acts take play during the darker hours of the day when most people are at home (shelter). Hence, the visibility metric should be sourced from the shelter itself. In this study case, the Al-Hol refugee camp was examined since the locations and orientations of shelters was available. Also, from the floor plan, the UNHCR’s family tents could be discerned. Most of the shelters, in this case, are tent models. These tents have two major openings for entrance at the opposing sides of the shelter, which may also serve to calculate view cones (Figure 49).

Figure 49 UNHCR family tent view cones

Having constructed the view cones for each of the shelters, we can then proceed to estimate how much percentage of the given road segment is falling under the view cone of one or more shelters. This can answer the question of whether the road segment is well observed or not (Figure 50).

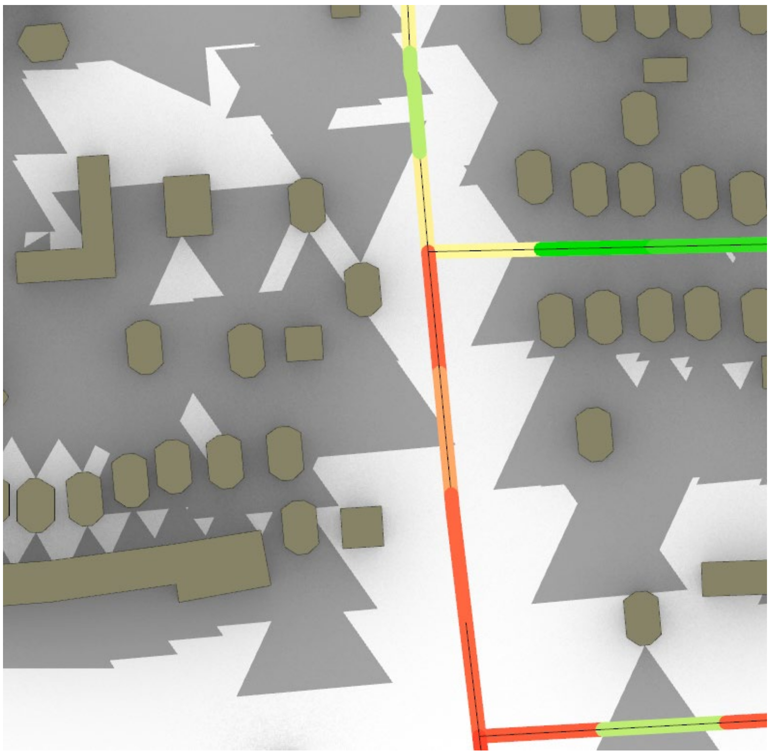


Figure 50 Road segment visibility estimation

The visibility metric of the road segment can be divided by its length to give the GBV risk index. So the less visible and longer it is, the riskier it becomes. By using this logic, a GBV risk map of the given camp can be estimated (Figure 51).

This methodology will, for sure, require calibration of the actual shelter locations, orientations and general principles on how do we define visibility. But what we can observe for sure is that by implementing it, we can have an understanding of the GBV risk of various road segments in relation to one another. In the Figure 51 map, we can clearly see which parts of the road network are the most risk-prone areas. As it could have been assumed, the circumscribing roads and segments in the outskirts are dangerous. But we can also see that some internal segments also have high-risk values.

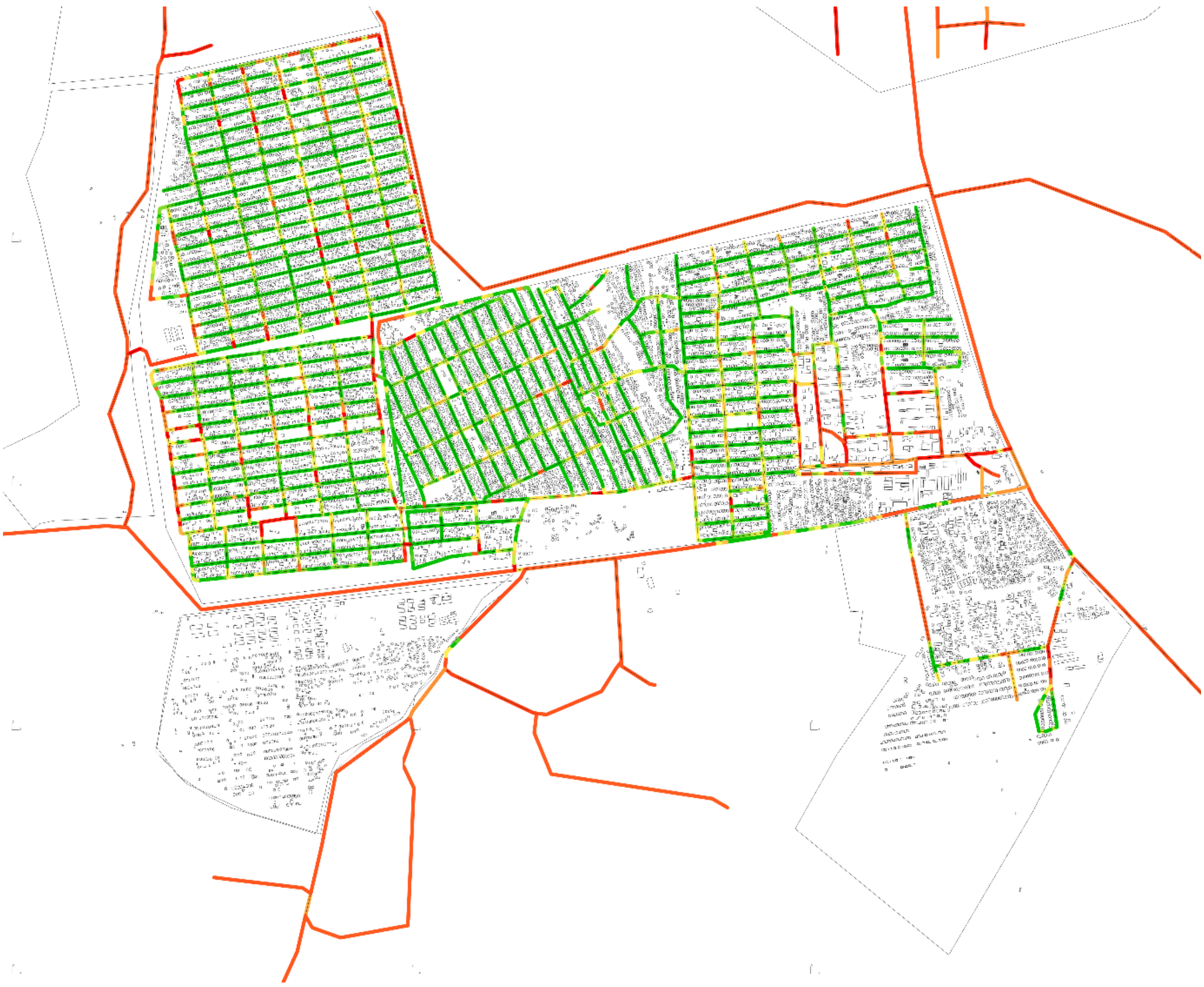


Figure 51 GBV risk map of Al-Hol road network

This methodology and tools can be implemented by refugee camp authorities in order to estimate the risk in the current situation and to take measures to reduce gender-based violence. Here again, a major factor would be the data available at hand. For instance, if the street illumination data is also available, it can also be integrated into the equation and produce more reliable results.

7.6 SHELTER PROXIMITY CHECK

One of the key guidelines established by the humanitarian agencies is the norm about how distant the shelters should be placed. According to UNHCR and Sphere Handbook norms, the shelters must be ideally far from each other by the distance twice the shelter height. The minimum would be two meters of distance (Figure 52).

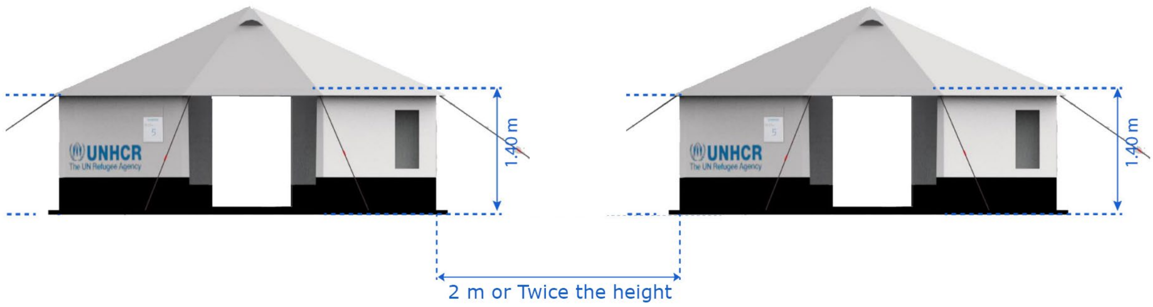


Figure 52 Shelter distance norm

By having the data about the actual shelter placements in the Al-Hol refugee camp from the Open Street Map, the following algorithm was implemented to check the compliance of the shelters there to this norm.

At first, for each shelter, the potential neighbours are estimated. This step reduces the calculation occurrences dramatically since, in this case, instead of checking the proximity of the shelter to every other possible unit, only the proximity to neighbours within a certain range is performed. For neighbourhood grouping, each shelter is represented by its area centre point. Then the neighbours are determined through the constructed RTree. Then for each shelter, the boundary curve proximity is checked between the current shelter and its neighbours. Here if any two points on the curve pairs are closer than two meters (the weaker norm is used), a red line is drawn to indicate this incidence (Figure 53).

Figure 53 Proximity violation check

In the entire Al-Hol camp, more than seven thousand such violations were detected (Figure 54). Al-Hol is known to be a problematic refugee camp. The purpose of this research is not to critique it but rather to demonstrate that such issues can be dealt with more efficiently. And first of all, in order to deal with such issues, they have to be correctly measured. The algorithm presented in this chapter effectively measures one key indicator in refugee camps.

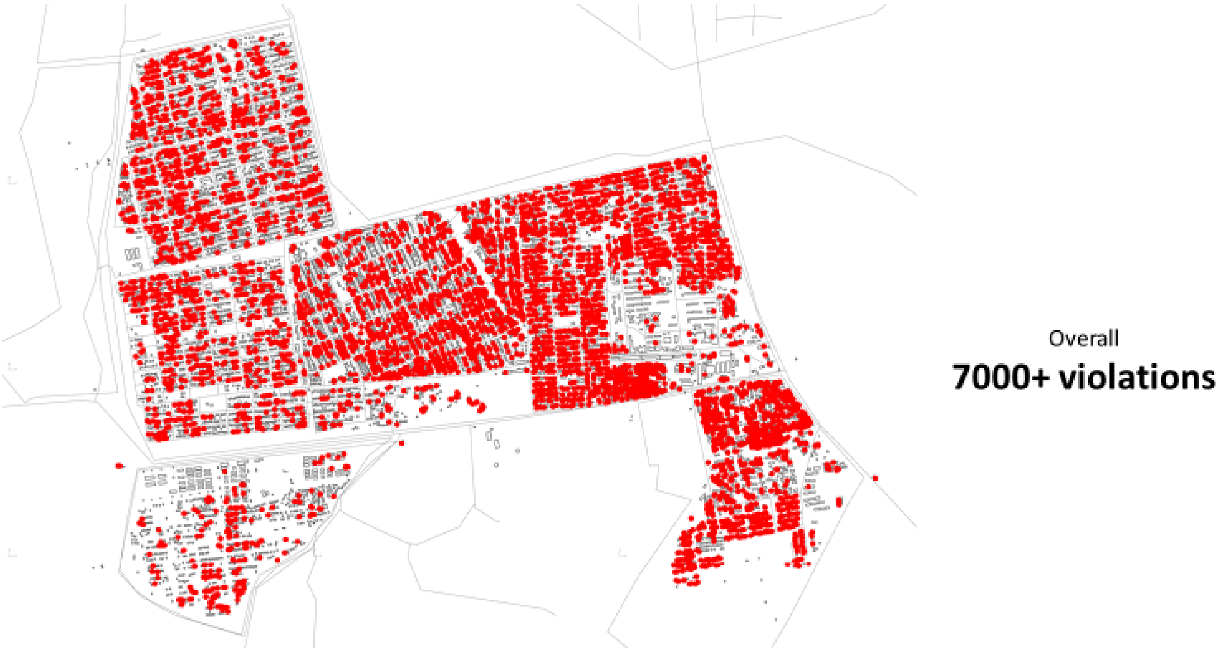


Figure 54 Shelter proximity violations of Al-Hol camp

7.7 CASE STUDY 4 – BALAT SETTLEMENT

7.7.1 OVERVIEW

The augmented flow of man-made conflicts increased consequent waves of millions of internal and cross continents displacement and migration. Consequently, there is a dire need for durable housing solutions for affected communities. Humanitarian architecture as a subdomain of architectural and urban planning disciplines is the one accredited for the service of the suffered population

This case study aims to make a step in this direction and to show practical applications of algorithmic modelling in refugee camp planning. This proposal is suitable for refugees residing from neighbouring countries that share common or tangent traditions, social norms, and cultural beliefs. That will make the transitions and move-in easy with a higher level of acceptance to the housing situation. This project will be focusing on Syrian refugees as, according to UNHCR, are the largest refugee population in the world. March 2019 marks nine years of Syrian civil war accumulating 5.7 million Syrian documented as refugees in 127 countries where the majority are residing now in Turkey, Jordan, Lebanon, Iraq, Egypt and other neighbouring countries in the Middle East. 70 % of the Syrian refugee population lack access to basic services [41]–[43]. The hope here is that this case study can help in offering hands-on solutions for decision-makers, architects and planners alike.

Not only this, but the outcome of this project also has another side of indirect benefit for and can serve as a way for conflict re-building for vernacular settlements that have been affected by post-war destruction and political dispute. It is well known common practice that to preserve a building is to use [44], [45]. The same goes for an entire settlement to keep it alive with inhabitants instead of having them as ghost towns and cities [46]. Vernacular settlements normally offer decent housing quality, which is not always the case in temporary refugee settlements with poor tent structures. The majority of the time, temporary shelters deteriorate quickly, are ill-adapted to the harsh climate conditions and lack the basics for family life, comfort and protection [47]. Vernacular settlements can fulfil and accommodate basic social needs for larger families with over three family members as the tradition in the Middle East. Privacy is always a major issue in refugee camps. Vernacular settlements can offer homes for each family to live together with lots of common shared social spaces where people could interact and socialize. Rehabilitation of vernacular settlements is to fulfil the basic needs of a contemporary lifestyle like providing electricity because the majority of vernacular settlements are off-grid or lack such infrastructure [48].

The aim here is to offer easy and quick methods for mapping, identification and evaluation of the suitability of transforming vernacular settlements into refugee dwellings and the same time, a way of preserving and rehabilitating such deserted settlements.

Nowadays, wars and political conflicts are some of the most common threats to vernacular architecture in conflict areas. On the one hand, destruction and vandalism cause so much harm to vernacular settlements. Also, vernacular dwellers were forced to leave their homes seeking safe-havens. On the other hand, how vernacular architecture can help refugee crises in host countries? Internal and external migration is not a new phenomenon, but forced migration is becoming extraordinary due to both armed conflicts and climate change. Billions of dollars are invested in establishing temporary refugee camps, and we know for a fact they are never temporary. People stay in such camps for years and decades.

Rehabilitation of vernacular settlements can be a clue. Vernacular towns and villages are normally located in the outskirts, which are the common places for refugee camps. Investments in rebuilding, resorting and reusing such settlements can be a win-win situation. It might go against some policies that refugee settlements could not be permanent or give a feeling to refugees that they will be here forever. Also, some challenges like the time for the rehabilitation process and cost might not be suitable if the camps to be built are cheaper and quicker. In this study proposal, re-using and rehabilitation for vernacular settlements will be discussed together with reflections on challenges and obstacles in addition to regulation for listed vernacular sites. The case study chosen for this research work is in the Middle East, where the majority of refugees are situated after the Arab springs. This case study demonstrates a methodology of applying algorithmic modelling to solving refugee settlement site planning and decision-making tasks.

7.7.2 Case study description

Figure 55 Balat (Photo from Wikipedia)

The town of Balat (Figure 55) in the Western Desert of Egypt is chosen as a case study. The town represents a typical earthen vernacular settlement that used to be inhabited by 3000 dwellers. Now only 20 % of its inhabitants are still living there. The rest left the town seeking modern buildings with better infrastructure and facilities [49]. The town has few water source outlets provided by the local municipality after the natural wells dried out. Also, the municipality provided the town with the main infrastructure for electricity. There are no sewage or wastewater infrastructure in the town, and mainly compost dry toilets are used. The town is vulnerable to quick deterioration due to lack of maintenance and neglect as the majority of its inhabitants abandoned it.

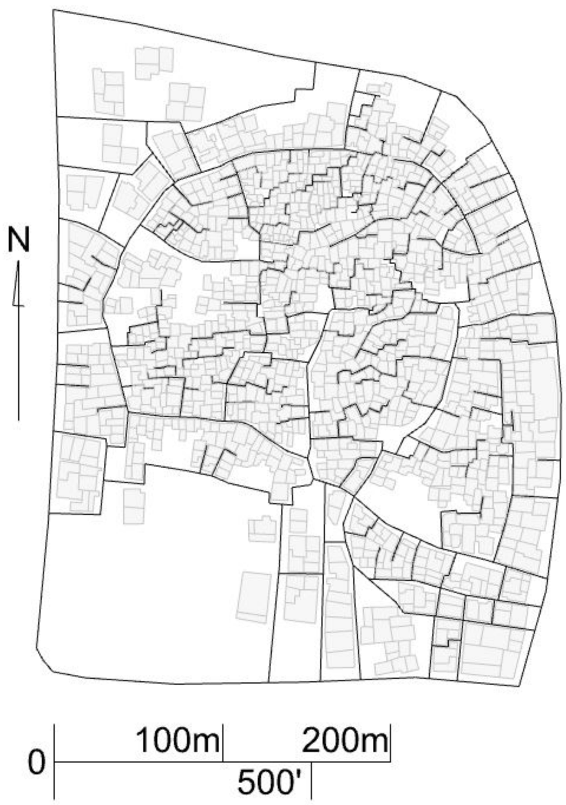


Figure 56 The central region of Balat

The application is chosen to be the central region of Balat (Figure 56) which is mostly comprised of mud brick vernacular buildings. Notably, the urban structure of it is as far from the modernist grid distribution as one can be. This is an important feature for the assessment of a settlement as a potential refugee camp. There have been many critiques about the urban structure of the refugee camps stating that although the grid layouts are efficient for monitoring and control, they do not bring the feeling of home to those who suffered [8]. This is especially pertinent to Muslim communities. On the other hand, the urban spatial structure like the one in Balat with narrow alleyways and small community clusters may be much more reminiscent of how people used to live. Small courtyards can foster neighbourhood interrelations and enhance the feeling of safety. In general, the notion of living in a camp is more repellent than the notion of living in a city. Rebuilt, repurposed but still a city.

7.7.3 APPLIED ALGORITHMS FOR SETTLEMENT DESIGN AND DECISION MAKING

7.7.3.1 POPULATION DISTRIBUTION MAP

At the starting point, the map drawing of the case study region was available [50]. The first task was to estimate the capacity of the settlement. At first, the residential buildings were selected. As a rule of thumb, approximately 30% of the plan area of those dwellings are dedicated to bedrooms. The UNHCR standards state that the minimum area per person should be 3.5 m^2. In cases where the cooking takes place inside the dwelling, which is what our case is, the area should be increased to be 4.5 m^2 [51].

A hypothetical assignment of the stories has been made to resemble the vertical stratification of the settlement. Having more precise data at hand, the model can be recalibrated accordingly, but the overall methodology would stay intact. Having the area, the hypothetical number of floors, the bedroom percentage area and minimum standard from UNHCR, we computed the number of people that each of the dwellings potentially can fit (Figure 57 and Figure 58).

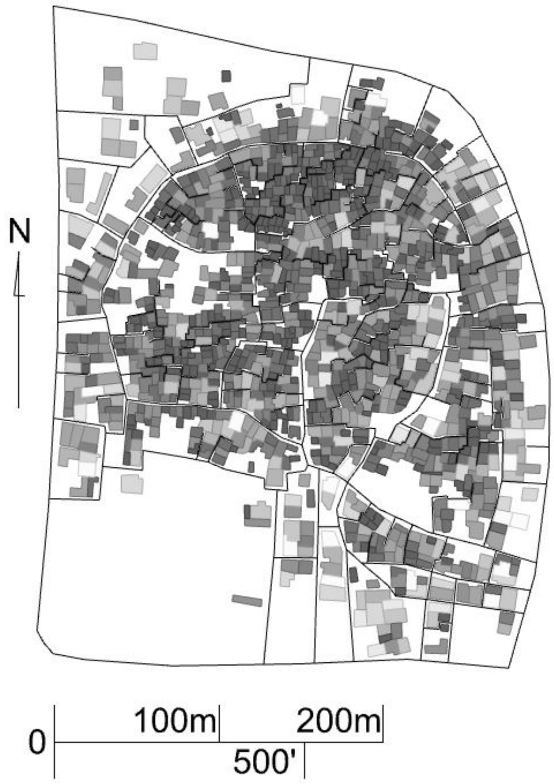


Figure 57 Weighted representation map

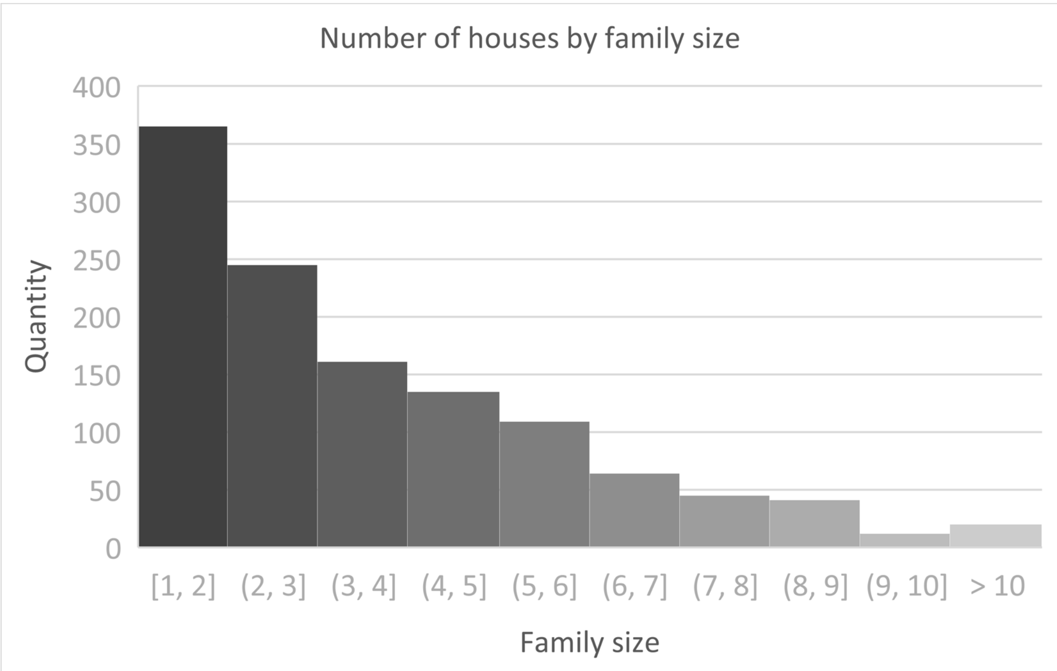


Figure 58 Houses per family size histogram

7.7.3.2 FIRE SAFETY CONCERNS

The fire safety standard of UNHCR demands the shelters to be at least 2 meters apart or better be apart with the length of twice of the shelters' heights. Considering that the settlements here are mostly built of mud walls, we can assume that the fire propagation will be highly impeded. Nevertheless, to address the fire safety issue, a connectivity diagram has been constructed to find clusters of continuously attached houses (Figure 59). As we can see, some clusters span more than 50 attached houses (one is even bigger than 300) (Figure 60) that can be of concern for fire safety. This analysis is aimed to aid the CCCM professionals in addressing the fire safety of the settlement.

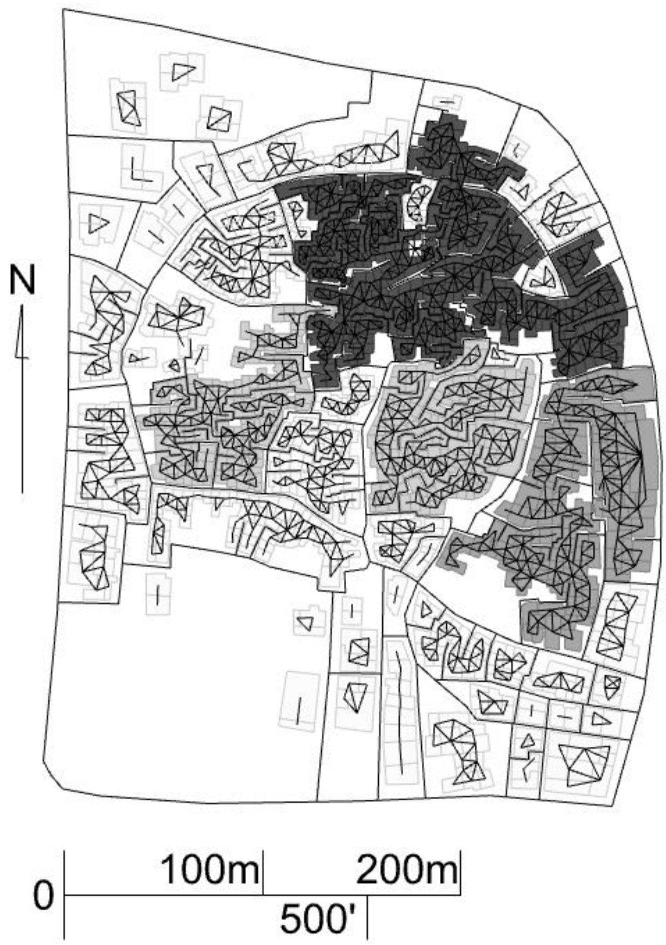


Figure 59 Connectivity graph of dwellings

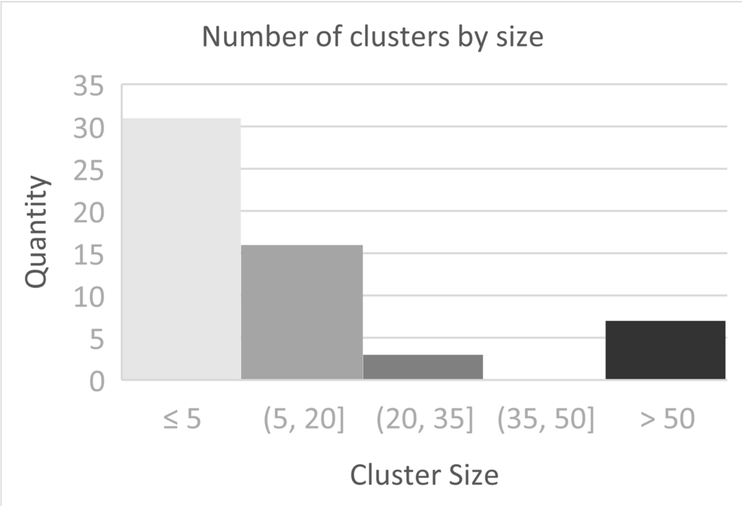


Figure 60 Cluster size histogram

7.7.3.3 DISTRIBUTION OF WASH FACILITIES

Another subject of consideration in refugee settlements is the WASH (water sanitation and hygiene) facilities. In our case study, the dwellings are equipped with compost toilets. However, there is no water distribution infrastructure capable of fulfilling the demand.
In this regard, the site planners have the task to place the water distribution points that will conform with the UNHCR requirement of a maximum 200m walking distance to the water distribution point. In our example, the settlement has a higher density than a grid layout refugee camp. Also, the path leading to the water distribution point is more convoluted. So, the study has taken an even stricter standard of no more than 100m walking distance. The objective is to find an optimal distribution of the water supply tanks (or wells if decided so) and to estimate their capacity.

The initial assumption is that the distribution points should be placed on the roads to be accessible for refilling by water trucks. Some parts of the roads are too narrow for a vehicle to pass through, so a minimum of 3.7m width is used to determine for each segment of the road network if it is suitable or not. For each segment of the road network, measurement points with a spacing of 2 meters are distributed. From each measurement point, two rays are shot on both sides perpendicular to the road tangent at that point. The distances to obstacles are added to get the width of the road at that specific point (Figure 61).
Afterwards, the segments that have at least one point with the measured width lower than

the threshold are excluded, meaning that the vehicle may not pass through there. The remaining pieces of the road network are tested on connectivity with the main circumscribing road. The disconnected pieces are also excluded leaving only the network that is accessible by vehicles (Figure 62).

Figure 61 Measurement of road width

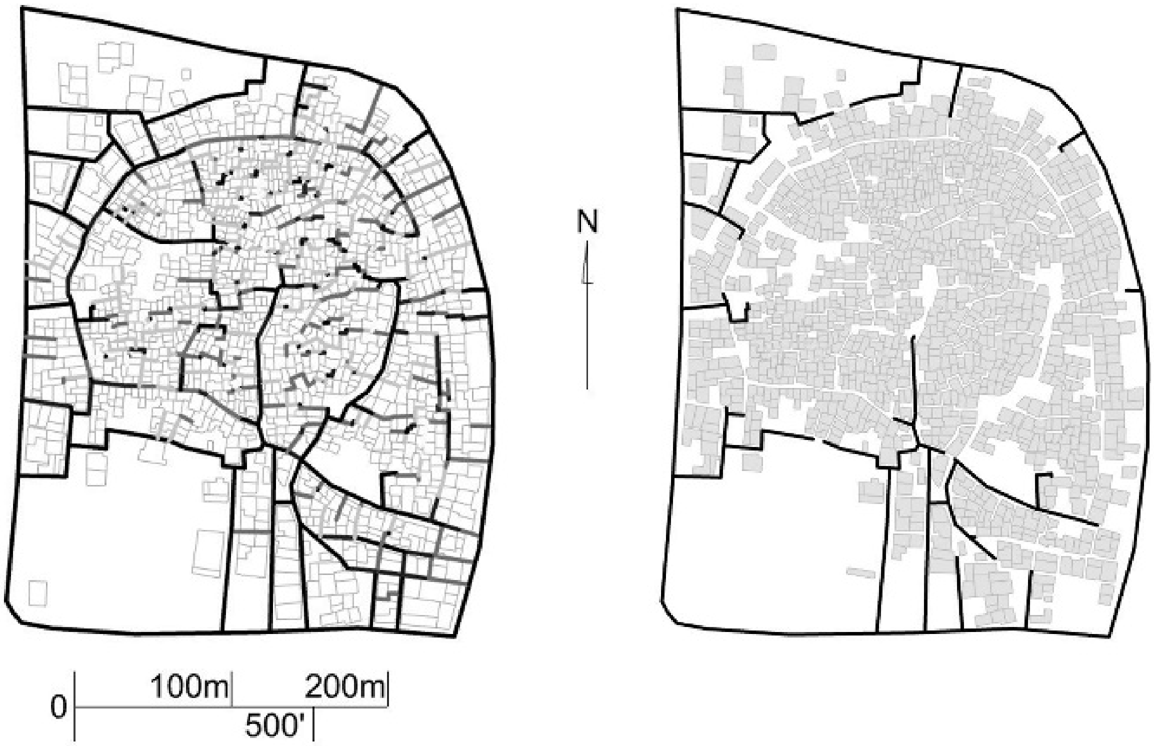


Figure 62 Road with map and remaining network

As stated above, the general assumption is that the water distribution points should be located on the roads, more specifically on the roads that remain after the width and connectivity purge. Thus, a series of potential points are distributed on the network with a spacing of 2.5m, indicating all possible locations (Figure 63). The task is to choose a few of those that will jointly cover the entire settlement.

Figure 63 All potential distribution points

Each of the dwellings is spatially represented by the area centre point with the weight of the number of people living there. From those collections of points, an RTree is created. Then from each of the potential distribution points, the proximity is calculated inside the RTree, finding all the dwellings that are within the 100m distance from that specific point (Figure 64). Then the estimated number of inhabitants of those houses are added to determine the number of people that each specific location can serve. Now from the collection of the distribution points weighted by their coverage, the one with the most coverage is selected. Assuming that the first distribution point is found, we exclude the dwellings that are covered by this one and also the potential distribution points that are close to the chosen one since their outreach zones would overlap with the chosen one. The remainder is a subset of the house population that needs to be covered and a subset of distribution points that can be used. The same process is recursively performed until all of the houses are covered with the water distribution network.

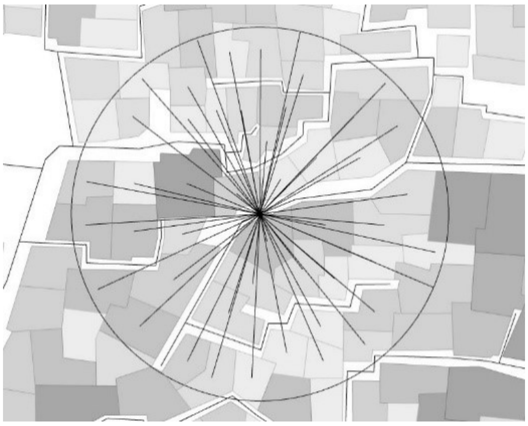


Figure 64 One distribution point outreach

7.7.4 Processing of the resulted distribution point map

The first result is the initial set of distribution points. This set is an optimal solution and ensures the coverage of all of the houses (Figure 65 left). However, further refinement is done due to several considerations. The first consideration is that if the inhabitants of a certain dwelling are within reach of two distribution points, they will most likely choose the closest one. Based on this assumption, the graph is adjusted to connect each of the houses to the closest distribution point (Figure 65 right). Then the next consideration is that within each distribution cluster, the points should be well-positioned, reflecting the needs of people within their cluster.

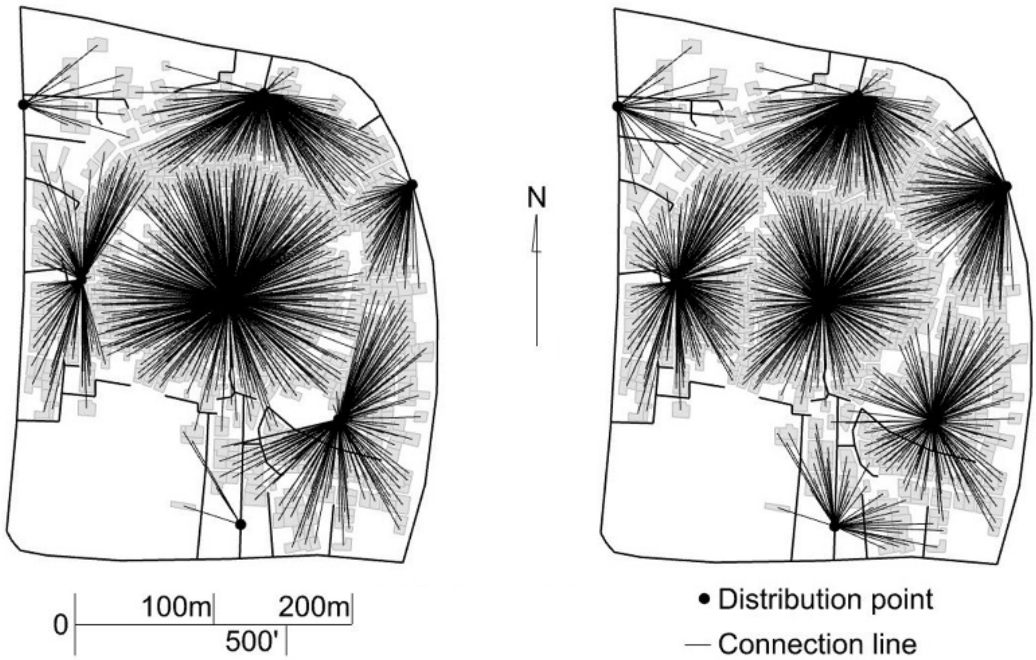


Figure 65 Initial distribution graph and proximity adjustment

The assumption here is that each house's inhabitants will tend to pull the distribution point closer to them. In order to model this, each connection line is modelled as a spring with the stiffness value substituted with the number of inhabitants living at that house by using Hook's law as the forces were calculated subject to the inhabitants' weight and initial distance. The further the house is from the distribution point, and the more people it hosts, the bigger the pulling force will be. The described force model was implemented in the Kangaroo physics simulation engine. Thus, we were able to simulate a spring relaxation which resulted in the updated positions of distribution points (Figure 66 left). Now since some of the points may have become out of the road network, they are repositioned to the closed point within the road network giving the final distribution of water supply points (Figure 66 right).

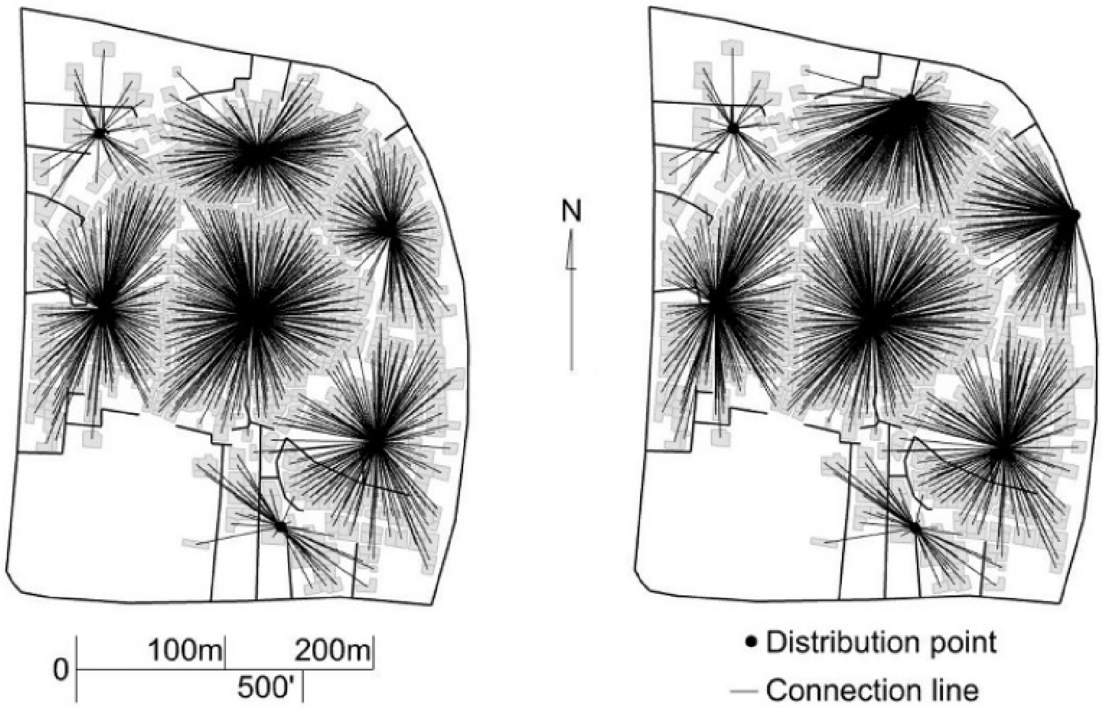


Figure 66 Adjustment by weighted forces and repositioning

The resulting walking distances to the allocated distribution points are calculated and plotted in a histogram (Figure 67). As we can see, the distribution is very optimal, with the majority of houses being placed on an average distance from the houses with only a few being very close and none being further than the designated 100m.

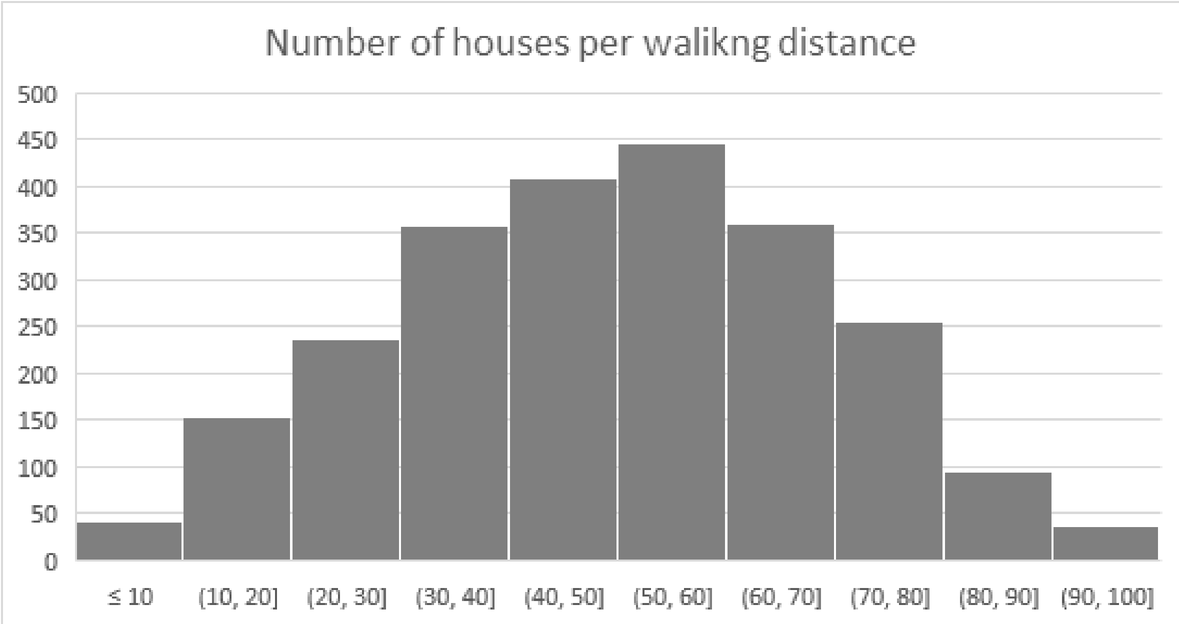


Figure 67 Houses per walking distance histogram

7.7.5 Alternative approaches

Computational modelling gives possibilities of many different approaches to the defined problem. This study case is one such approach. It is worth mentioning that similar problems are tackled in the field of operations research, and some mathematical disciplines such as linear programming can be adopted for decision making. An example of such optimization techniques can be the Simplex algorithm. Unfortunately, so far, the linear programming algorithms are not yet widely implemented in the existing graphical algorithm editing tools. Aside from this, the implemented tools include several genetic optimizations and machine learning algorithms that can be tailored to deal with specific problems of humanitarian architecture.

7.7.6 Case study conclusion

This case study research aimed to develop a methodology for solving refugee camp site planning and decision making through bespoke algorithms and computational models. The developed algorithms were able to yield detailed data-rich analyses of inhabitation density, fire safety and road access of the examined vernacular settlement with an intricate spatial structure. Also, the algorithms helped in decision making for the optimal placement of water distribution points. This study shows that the implementation of such techniques can result in creating better refugee settlements.

The proposal hopefully offers a solution for establishing a peaceful and safe society through re-using existing vernacular settlements that have the protentional in reducing social inequality by offering equal access to services within decent shelters that resembles a stable society. Besides, rehabilitation of existing vernacular settlements can provide privacy, protection and better living conditions for refugees, which are pivotal requirements to start a recovery and reconstruction programme after a disaster. On another level, hosting refugees in a community like built environment will help in reducing the trauma effect and will speed up healing and recovery when they feel like being in a home rather than a tent.

SECTION 2:

SHELTER

8 SECTION 2 – SHELTER

8.1 INTRODUCTION TO SECTION

This chapter will present advancements in the technology of design and assessment of refugee shelters. The following two chapters are dedicated to a particular type of shelter, which is tents. Since they constitute a very big portion of humanitarian relief content, any advancement in this domain can have a global impact on the early stages of emergency response. The third chapter will present studies on the internal thermal comfort of tents.

8.2 AN ALGORITHM TO DRAW SIMULATIONS OF DYNAMIC, LIGHTWEIGHT STRUCTURAL SYSTEMS WITH SCHEMAS

8.2.1 DESCRIPTION

Architects, designers and structural engineers throughout their education and practice work mostly with visually controlled 3D modelling applications that require manually controlled actions to get the final desired model. On the contrary, we can see the development of visual programming that is now intertwined with traditional software applications and uses data flow to generate geometry. Professionals in the AEC industry witness the capabilities of visual programming, mainly using its output and the live demonstration of scripts that automate the big amount of manual work. Although visual programming is very appealing as an asset, acquiring the necessary skill set is often a matter of struggle. An example of this is the dynamic simulations of structural systems (tensile, bending active, etc.). There are means to perform them, but they usually require knowledge of visual programming and several frameworks. This chapter introduces an open-source algorithm cutting short the intricate process of learning new non-conventional software and directly allowing designing dynamic structural systems as a schema and getting the instant simulations therein.

8.2.2 USED TOOLS

Rhino 3D CAD software is the environment where the designer creates the model(schema) of the structural system. The visual programming plug-in Grasshopper is the place where the algorithm is assembled. The fundamental basis of most computational systems used for the design of surface structures is some form of equilibrium modelling [26]. This equilibrium is achieved by the Kangaroo package, which is an interactive physics/constraint solver.

Elefront is a plug-in package for both Rhino and Grasshopper together that allows the automated transfer of properties between one another and enables auto-referencing of geometry [52]. For representation, a package called Human is used since it creates a pipe-like thick representation of linear elements without affecting the performance heavily. Some parts of the algorithm are developed with Python and C#.

8.2.3 The algorithm workflow

When the designer runs the algorithm, it generates a set of layers that will be used by the designer to identify component types. No input from other layers is considered, and even the elements present in working layers are filtered to match their proper use. For example, the linear elements in the membrane layer will not be taken into account.

The indication of the element type triggers the creation of appropriate properties for that element that the designer can use to input values. These include strengths (non-structural arbitrary quantity for Kangaroo solver), length goal factors, snaping planes for rigid objects and more. The complete list of parameters is listed in Table 5. The updated elements with imported values are referenced again.

Later the referenced elements pass through chains of geometrical modelling. This includes:

8.2.4 Interdivision of linear elements

Kangaroo 2 engine works by leveraging the position of the points that comprise elements in regards to the active collection of goals. If we want an element to interact with another one, it must have at least one common vertex. In this regard, all the points that lie within the given distance (a number close to 0) from a linear element will act as a division point. This includes the intersection events between all linear elements, anchors, loads and boundary defining points of membranes (Figure 68).

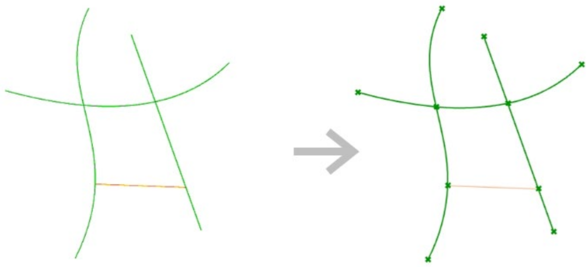


Figure 68 Intersection event of different elements

8.2.5 Graph connected components

In order to let the designer draw connected rigid components, it was necessary after solving the intersection events of curves to group them by connectivity. Here a sub-algorithm is used to perform flat hard clustering based on curve-curve intersection events. It creates clusters of connected components in the graph. In Figure 69, the nodes represent curves. If the curves are intersecting (including end-to-end connections), then there is a connection line between those nodes. The algorithm clusters together all the connected curves and gives indexes of the curves from the initial unordered list as a data tree.

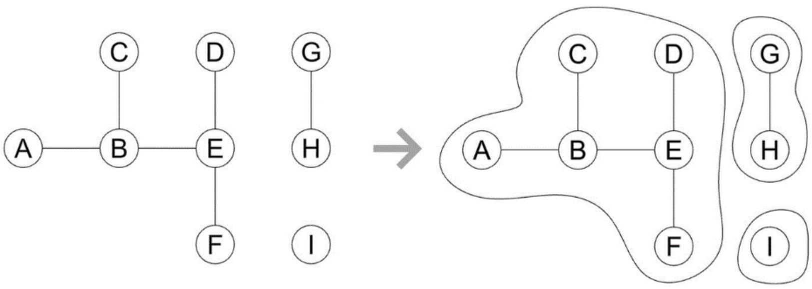


Figure 69 Graph connected components clustering

8.2.6 Segmentation

Since Kangaroo 2 works with points, to simulate the behaviour of curved elements (rods, cables, etc.), it is required to divide the designed curve elements into several linear segments (Figure 70). Precision is one of the designer's inputs. It is usually based on the scale, the complexity of the project and the computing power of the used processors.

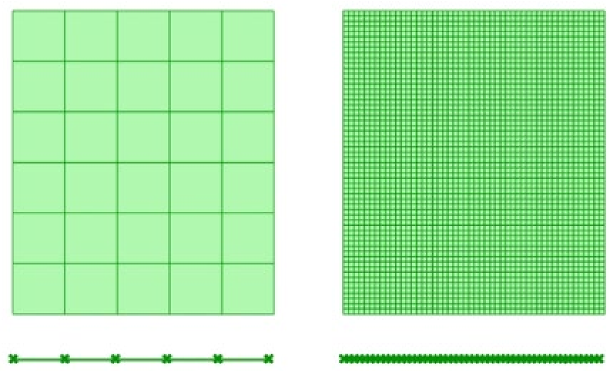


Figure 70 Low and high segmentation controlled by segment size

8.2.7 Membrane adjacencies

One of the challenges in simulating the membranes with Kangaroo is the solution of adjacencies of different membrane meshes with non-matching edge vertices. In these cases, since there is no vertex wise superposition, the meshes act as separate units. As an inherent part of this algorithm, a special part is written to address this issue. It finds the connected edges between membranes and creates local goals of collinearity for each point with the nearest two points on the other membrane. This ensures that the seams are correctly simulated. The designer has the choice to weld or not different membranes (Figure 71).

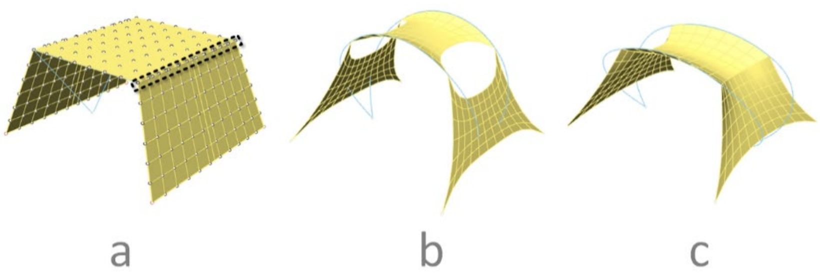


Figure 71 a) drawn model b) separate membranes c) joint membranes

After the presented geometrical operations, each group of geometry is composing a goal of the Kangaroo 2 engine. The necessary parameters are passed through the designer's input. The structural and representation goals are combined into an ordered data tree and are inserted into Kangaroo 2 solver. Each time the designers changes the schema, the whole script is recomputed, and the simulation model is updated to include the altered schema elements.

8.2.8 GEOMETRY ANALYSIS

The algorithm post-processes and analyses the simulated geometry. Curve-like components that were segmented for simulation are re-interpolated into curves. These curves are used to generate curvature values and provide dynamic output as a curvature graph on top of the model with corresponding numerical values of curvature (Figure 72). It also tracks the mean curvature values of the membranes. Although in this case, there is a back and forth translation to a surface object which may reduce the accuracy (Figure 73).

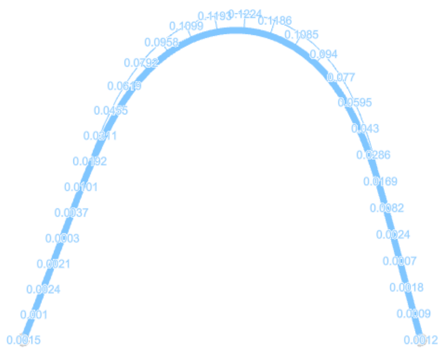


Figure 72 Rod curvature graph

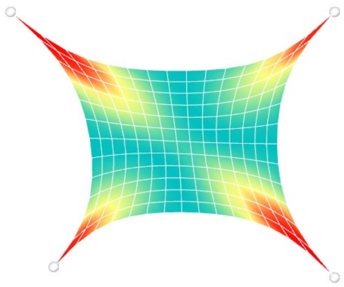


Figure 73 Colored representation of mesh curvatures

Figure 74 depicts the flow chart of the entire algorithm.

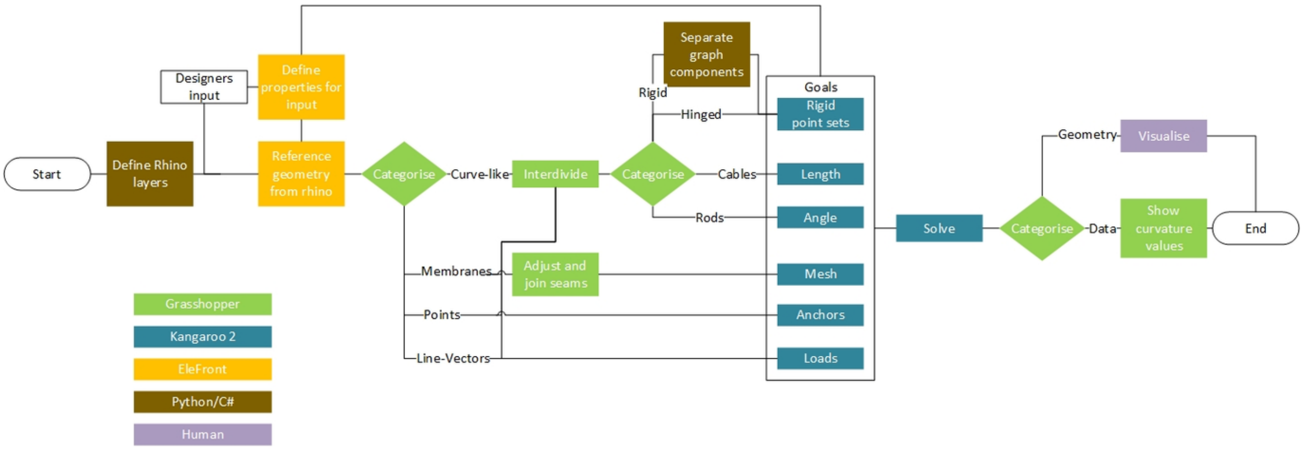


Figure 74 Macro process flow chart of the algorithm

8.2.9 Use cases

In order to validate the algorithm, many different design solutions were tested to see if it correctly carried out the simulations. The tool was distributed to the students of the lightweight structure design class, and their feedback was taken into account to expand the capabilities of the algorithm continuously. This includes the possibility to snap rigid objects to planes, join membrane seams, insert individual strength values and many more. Some of the use cases are described below.

8.2.9.1 Gridshell

Conventionally it is possible to simulate a gridshell with the Kangaroo 2 engine. However, it takes some effort and knowledge of both Grasshopper and Kangaroo. With the help of the algorithm, the designer only has to draw a flat network of rods, lines that represent the initial and moved positions of the anchors and a load vector line to lift the structure. This workflow is intuitive. Figure 75 shows the interaction between rods, moveable anchors and a load.

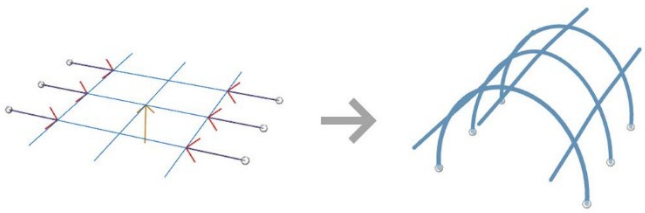


Figure 75 Gridshell schema and the ready model

8.2.9.2 HYBRID STRUCTURE

Hybrid structures are very tedious to model since the joint elements of various structural types close require precise modelling, and in the case of simulation with Kangaroo, they also require a matching segmentation and anchor positioning. The algorithm streamlines all these processes, and the schema that was drawn by the designer is effectively transformed into a correctly interconnected hybrid structure. Figure 76 shows the joint simulation of anchors, membranes and a rod.

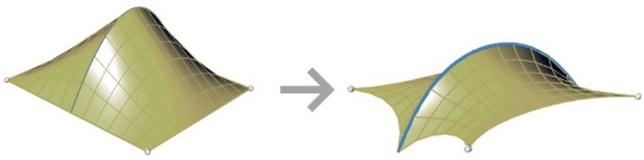


Figure 76 Hybrid structure

8.2.10 CONCLUSION

The research aimed to investigate the possibilities of streamlining the workflows of manual creation of Grasshopper+Kangaroo algorithms that are required to perform simulations of various structural systems. As a result, a robust algorithm was developed that works intuitively for the designer to translate the drawn schema into a simulation model and get instant geometry analysis data.

8.2.11 INTEGRATION OF STRUCTURAL ANALYSIS

The form-finding process based on the Kangaroo particle simulation engine is at first done with arbitrary strengths. This means that any given strength value for a goal like a membrane tension or the bending resistance in rods is governed by a numerical value that does not represent any mechanical property that the structural element has. This is useful enough to get a general intuition on how different elements with their own behaviour work as a whole in relation to each other. This does not, however, give any meaningful data about actual stresses that the elements will have; thus, it may not be considered valid for the final design.

Fortunately, the intrinsic properties of the Kangaroo engine (K2) are such that they allow manipulating them in a way that actually stresses may be derived. This is exactly what Cecile Brandt has done in her master thesis, developing the overlay of the K2 engine called K2Engineering [53]. Her framework works with the same logic of K2 by taking various goals that do act upon points comprising structural elements. Her added value was that she substituted arbitrary strength values of K2 with actual stiffness parameters like Young's modulus and added the output for actual stresses, bending moments and so on.

Limitations here are the following:

1. Overall the framework is somewhat simplistic for a structural analysis environment. The structural elements to be used are Bar, Beam, Rod and Cable. Membranes can be represented as networks of cables. It is not possible to make in-depth evaluations of various regions of the elements as in common finite-element structural analysis environments.
2. As it performs a form-finding and deformation analysis at once, the large deformations of elements may be considerably slower to execute in comparison with the conventional K2 workflow.

The first limitation can also be considered as an advantage since the framework presented here is targeted to be used by architects and not structural engineers. As the framework overall is designed to be used in the conceptual design stage, the simplicity of K2Engineering will allow to perform initial tests and discard unsuitable designs right away. This includes the actual structural performance of the assembly and its behaviour under wind and snow.

The second disadvantage was overcome in the developed framework in the following manner. Having at hand two possible alternatives K2 and K2E, where the former lacks specificity but has speed, and the latter has actual stiffnesses but is slow, the overall simulation was divided into two parts, as shown in Figure 77.

1. At first, the large deformations of form-finding are performed by the base K2 goals achieving fast results. The resulting geometry may not be accurate, but it would be much closer to the final outcome than the schematic model from the start.
2. Then the K2 form-found model is used as an input for the K2E, this time coupled with actual stiffness properties. The remaining calibration work is done with K2E, achieving more accurate results and stress outputs.

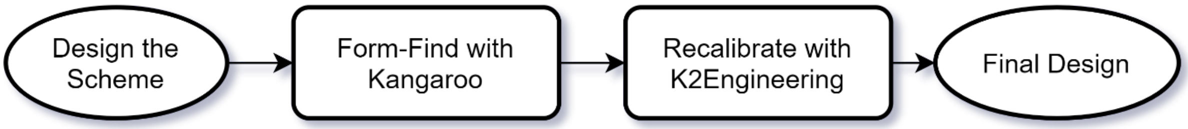


Figure 77 Combined workflow of Kangaroo 2 and K2Engineering

Figure 78 shows a simple example of an anchored cable network with pretension. At first, the drawn scheme is form-found with length changing goal for the lines that represent the cables. Then the actual physical properties of each cable are input to achieve an accurate result. As evidently shown, the difference between the first and second models are much more drastic than between the second and third. This combined workflow ensures a more efficient user experience.

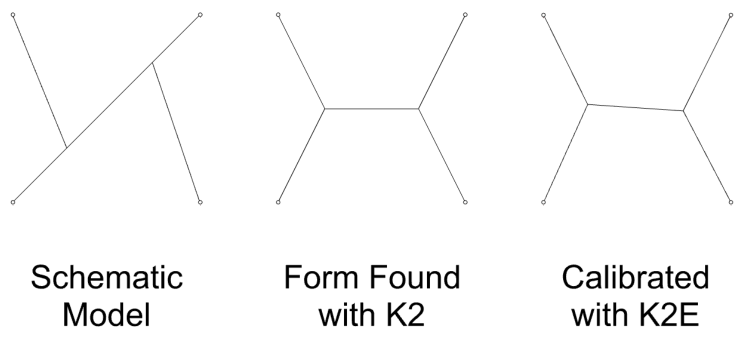


Figure 78 Example model that went through the two-step simulation

The detailed list of inputs that are used for the two consecutive simulations is given in Table 5. Any selected element has to access to all inputs a list of properties that a user can write. However, based on which step of simulations is taking place, only the necessary ones will be taken into account.

Table 5 Input fields of elements for K2 and K2E simulation

Goals\Elements	Cable	Membranes	Bar	Rod	Anchor
Kangaroo 2 Goals	Goal Length	Goal Length	Strength (arbitrary large value)	Angular Strength (Bending Resistance)	Strength (arbitrary large value)
	Strength	Strength		Axial Strength (arbitrary large value)	
K2Engineering Goals	Young's Modulus	Young's Modulus	Young's Modulus	Young's Modulus	Strength (arbitrary large value)
	Density	Area Density	Density	Density	
	Diameter	Thickness	Diameter	Diameter	
	Pretension force	Pretension force			

8.3 ALGORITHMIC DESIGN AND EVALUATION OF EMERGENCY SHELTERS

8.3.1 OVERVIEW

This chapter will demonstrate how the algorithm presented in the previous chapter can be used to design a shelter through modelled design cases.

To help humanitarian architects design more intuitively and efficiently, a semi-automated design workflow is developed that automates the geometry relaxation setup and design validation analysis, meanwhile leaving the creative and decisions making responsibilities to the architect. An attempt was made to bring the developments in architectural technology of the last decade closer to humanitarian architecture.

This research is the successor of the paper presented in the Tensinet symposium [54], which in its turn was based on the earlier work done in CITA [13], [55]. The previous chapter presented the workflow algorithm that streamlines the design+simulation process that otherwise would require expert knowledge in visual programming to make it more intuitive and accessible for designers. The algorithm reads the geometry from the 3D modelling environment along with its properties assigned by the designer and generates the necessary behaviour to give back instant simulation of what has been drawn. This includes the deformation simulations of cables, rods, membranes, and rigid objects. Thus, the architect can make design simulations without knowing how to program the behaviour.

As a successor, this research shows the application of the earlier developed algorithm in the domain of humanitarian architecture. Shelter design cases are presented that show the benefits of the developed tools' usage. The algorithm is extended with analysis and validation procedures that are also presented in this thesis.

Due to the nature of structural elements used in emergency shelters, the geometry of such objects often has very large deformations, curved shapes and double-curved surfaces. In contrast to rectilinear objects that architects can handle easily, the largely deformable objects are not always so easy to model. The overall shape of the designed object highly depends on the topology and reciprocal influences of one element on the other. In this sense, each of the elements has a certain degree of uncertainty of how it is going to look in its final shape. The shape of the membrane cover of the tent will change depending on the type of frame that is holding it and the boundary conditions. So, if, for example, an architect adds or removes a tensioning cable for a tent, the overall geometry and the deformation of each affected element change. Redrawing the new state of the design can be an arduous, time-consuming task. In this regard, the developed algorithm suggests a simpler rectilinear, flat definition from the architect that defines the topology and overall shape of the design intent. The algorithm then parses the model and redraws the actual deformation that the model will have. The simulation is an ongoing process, so it responds to any change that the architect makes and instantly draws the updated deformations.

8.3.2 Design cases

8.3.2.1 HYBRID FRAME TENT

Figure 79 presents the design of a shelter that has rigid-bending active hybrid frames that hold the textile cover. The structure is tensioned by four cables anchored on the opposite side of the shelter. The left part shows the scheme that the architect makes. Various types of objects are given in different colours. The design scheme has only linear and flat geometries drawn. But since they are indicated as representatives of a certain kind of behaviour, they are deformed in the relaxed state of the geometry on the right. As the image shows, the cables have become shorter due to pretension; the membrane switched to an anticlastic form to reflect the acting forces; the bending active members are bent and so on. If we compare, the only things that maintained their exact positioning are the anchors on the floor.

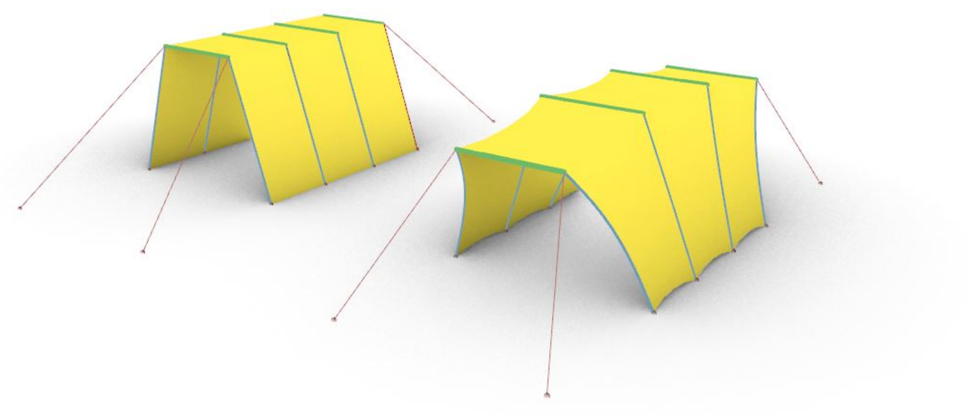


Figure 79 Hybrid frame tent

8.3.2.2 BENDING ACTIVE MODULAR SHELTER STRUCTURE

Figure 80 presents a modular design of a shelter that is framed by bending active rods holding the membrane between three equilateral sides of a module. This example particularly shows the advantage of using the algorithm since the membrane between the three frames has a very complex shape. However, from the architect's perspective drawing a scheme that will result in this complex shape becomes fairly easy. Each membrane piece requires only four boundary points defined on a floor anchor, tips of the frames and the tip of the module. The drawn modules can be replicated. The open ends of the modular structure are tensioned with cables.

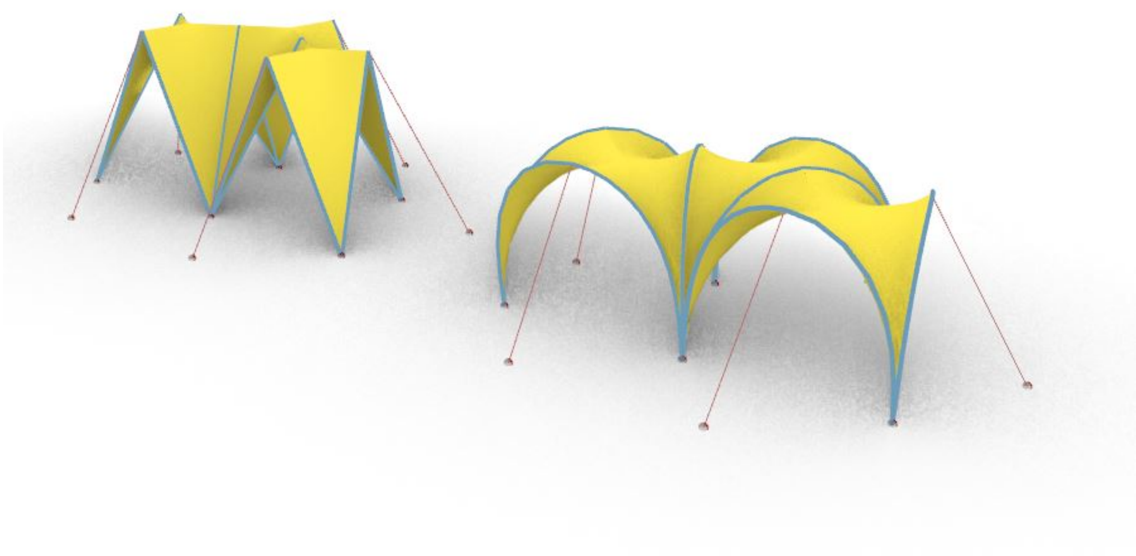


Figure 80 Modular bending-active frame tent

8.3.2.3 VAULTED HYBRID

The power of the proposed algorithm and method of design is also evident when the designed scheme yields unexpected results. For example, when working with bending active members, the common way of envisioning the forms of the rods would be to draw arches with continuous curvature. Figure 81 shows a design that has a major rod that forms the vault. The natural way of imagining the relaxed state would be to assume a paraboloid looking arc. This would be in the case when the rod has very high bending resistance. But if we decrease the bending resistance, the membranes' and cables' tensions may start deforming the arc. As it is shown in the image, the rod has deformed in a way that the direction of the curvature is changing along the way based on the balance of the forces compared to its bending resistance.

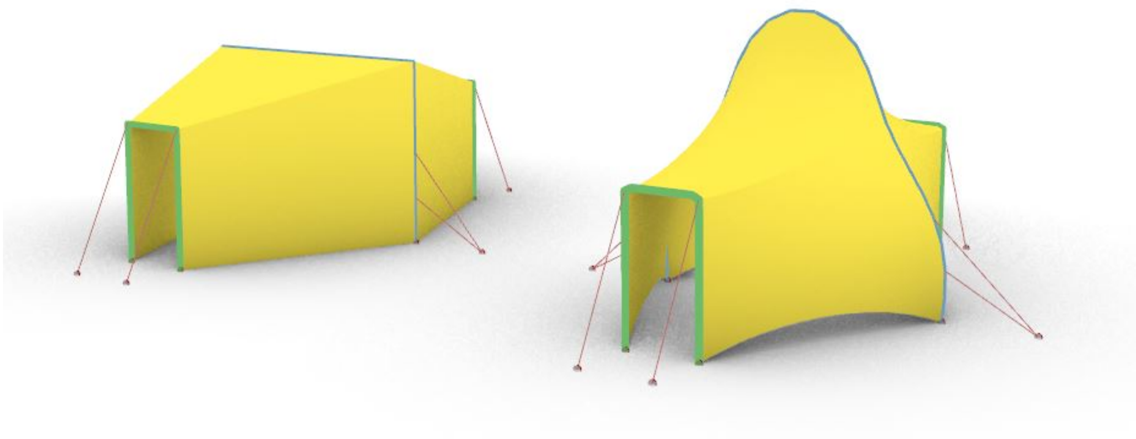


Figure 81 Vaulted tent

8.3.2.4 X ROD SHELTER

Figure 82 shows a shelter that has bent rods to hold the membrane. The interesting part here is the different types of interdependencies of various segments of the rods that are drawn as lines in the scheme on the left. The following three scenarios are presented within this model.

1. One segment continues the other as an internal sequential segment of the same curve. This is true for the longitudinal sides of the angular curves that span the shelter. They are drawn as polylines. The polyline is then segmented and tries to straighten up itself by opening the angles between each segment.
2. The x-like intersection of the two polylines. Whenever two polylines intersect within a given tolerance, an intersection event takes place. The algorithm makes sure that the intersection point is added to both polylines and the two corresponding points are bound together to make sure they hold together throughout the simulation. This behaviour is also true for the other type of intersections cable-cable, rod-cable, rod-rigid etc.
3. The end to end intersection of the entrance arch and the vault arcs where an anchor is also placed. In this case, although one segment can be thought of as a continuation of the other, the two intersecting parts are not part of the same polyline and will not apply bending resistance at that point. Therefore, there will be no continuous curvature at that point as shown with a red circle.

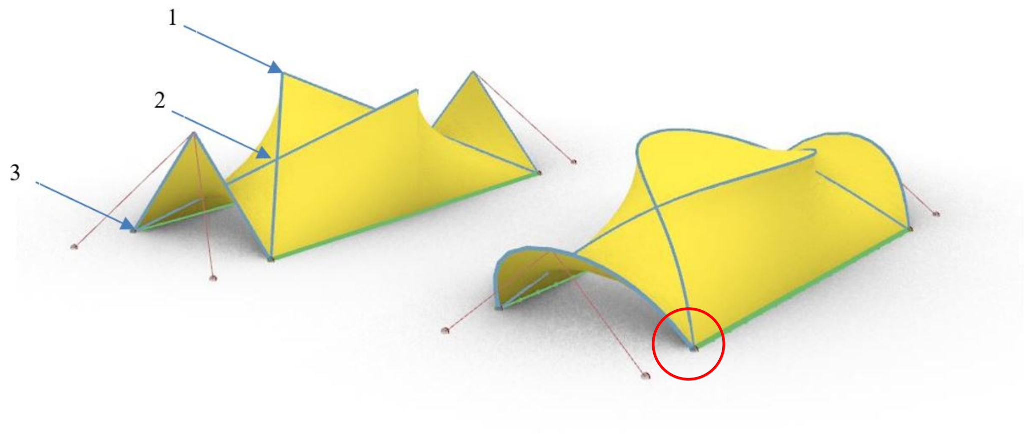


Figure 82 X Rod bending-active arch tent

8.3.3 Geometry analysis

The resulting geometry of the simulation is passed through several analysing processes. This includes:

- The creation of a rod curvature graph with curvature values at every point on the rod that is created from the intersection division and further subdivision (Figure 83).
- The drawing of the coloured mesh is based on the evaluated curvature (mean/Gaussian) at the mesh topology points. This is done alternatively through 2 different modules. The first one developed during this research is a method to translate a mesh to a NURBS surface, evaluate the curvature, then map the curvature values back to the mesh as a parameter for colour-coding. This method, however, has its limitations, so an alternative is to use is a Mesh Curvature package developed by Petras Vestartas [56] (Figure 84).

- Comparison of the lengths of the mesh edges to their initial state and a coloured wireframe diagram to show the parts where the edges were elongated or contracted (Figure 85).

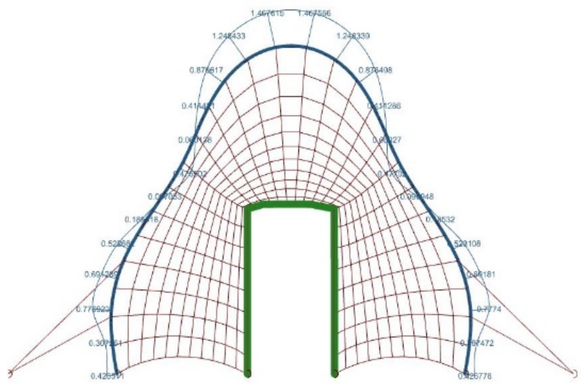


Figure 83 Rod curvature

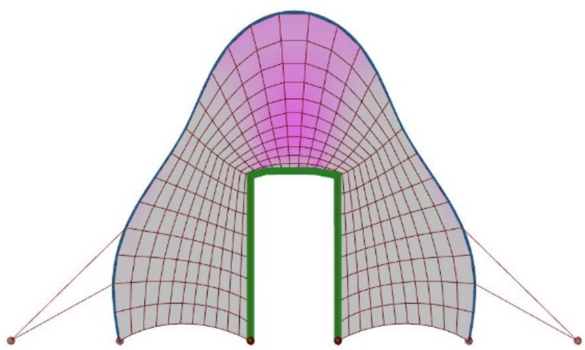


Figure 84 Membrane Gaussian curvature

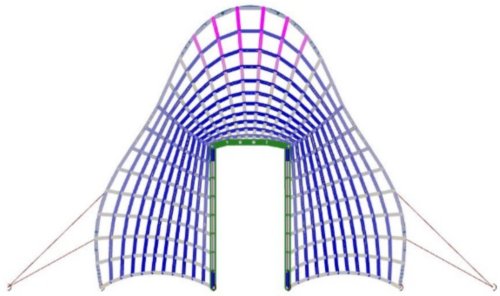


Figure 85 Membrane strain

8.3.4 Cutting patterns

The transformation of meshes to NURBS surfaces is also used to create cutting patterns for fabrication. At first, the longer side of the surface is determined. Then a new quad mesh is recreated based on the given cutting pattern dimensioning preferences. The stripes of quads are extracted, unrolled, reoriented to a distribution grid. The welding slits are added, and a numbering sequence is created to show the corresponding positions on the 3D map of the cutting patterns (Figure 86). The finalised patterns are then nested onto given fabrication sheets with the help of the "Open Nest" algorithm by Petras Vestartas (Figure 87).

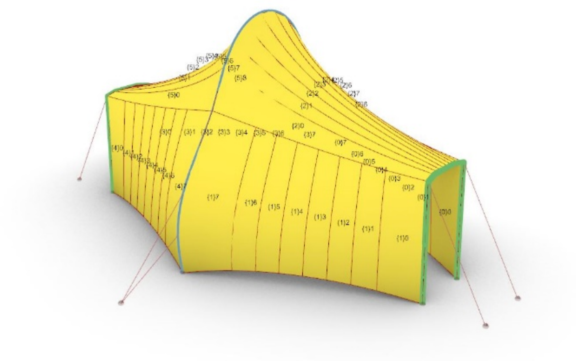


Figure 86 Membrane cutting patterns

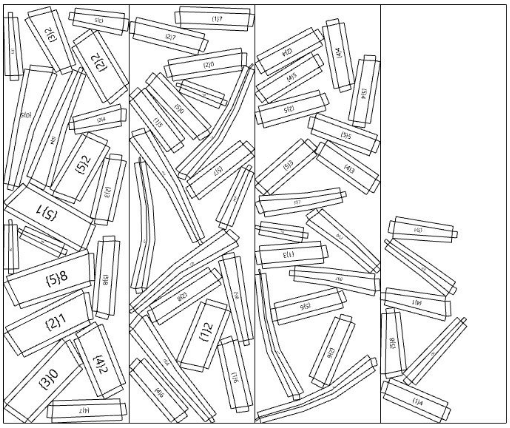


Figure 87 Nested cutting patterns

8.3.5 Compliance with UNHCR norms

There have been several publications from various entities that define standards for emergency shelter design. Widely accepted standards are developed by big humanitarian actors such as UNHCR [5], [57], [58].

This UNHCR standard defines that the area per person inside the shelter should be 3.5m² for hot climates and 4.5m² for cold climates. It also defines the standard for the height to be 2m at the highest point [58]. Those standards, however, do not describe much about the quality of the space within the area and height limits. Figure 88 shows three different section diagrams of shelters that all comply with the standard of 2m at the highest point. They may also have the same area underneath the roof. However, some shelters may have superior comfort compared to others due to their shape, even though standard-wise, they all are equally good.

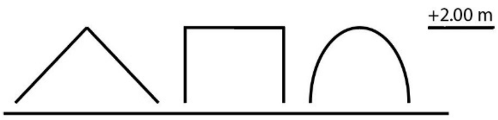


Figure 88 Different sections with the same height

The covers of shelters are often made of technical textiles. Those have inherent structural characteristics that predetermine the shapes that they can have. And those surfaces often have non-flat, anticlastic shapes that ensure tension in both opposite curvature directions [59]. This means that the geometry will consequently have varying heights, and as such, the singular dimension of the height at the tip of the shelter will not be sufficient to describe the height of the shelter.

To better describe the quality of the shelter in regards to its height, a measurement method is proposed that is also integrated into the design algorithm to give instant feedback to the designer.

8.3.6 Measurement method

The proposed method requires the algorithm available at hand to execute height measurement compared to measuring just the tip height of the shelter; however, it provides qualitative and quantitative insights on how well does the given design work. Given the fact that the shelters are limited in space, a deeper analysis of the shelter's internal geometry is necessary to ensure better living conditions inside.

Since the element defining the covered area are surface elements, the analysis is based upon meshes that represent the cover of the shelter. At first, the convex boundary of the shelter on a horizontal plane is determined. The convex boundary serves as a plot for populating the measurement points. An almost quadratic grid is created within the bounds of the convex boundary. The precision is controllable by the architect. Each quad of the measurement grid calculates the distance of the four corners to its vertical projection on the cover. Then the four corner values are averaged to represent the height at that quad (Figure 89).

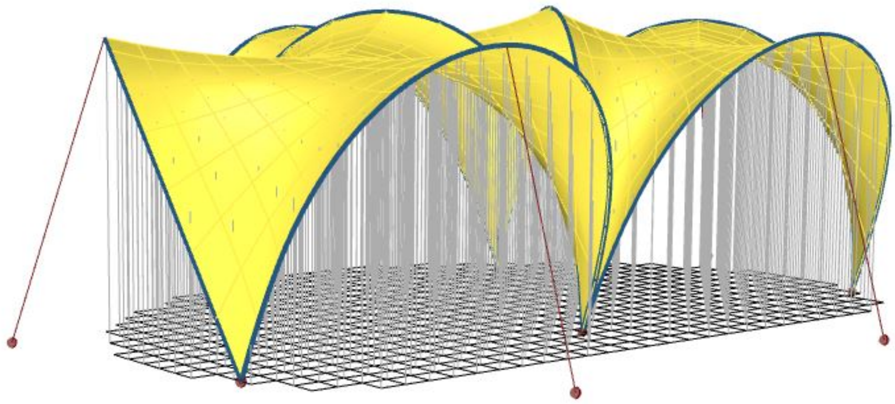


Figure 89 Shelter height analysis

The heights' dataset is then visualized by the following means:

- A controllable colour diagram is created that defines the lower and higher bounds for the measurement and the interpolation steps for the data. Usually, the higher bound should be coloured as the standard towards which the shelter is designed. A bar chart is created to represent the percentages of the area that fall under each of the height steps. This is crucial for understanding how much of the area is applicable to various types of activities that require a certain height (sleeping, cooking, etc.). Also, the covered total area, the highest point and the number of people they can fit inside (according to the standard) are given (Figure 90).

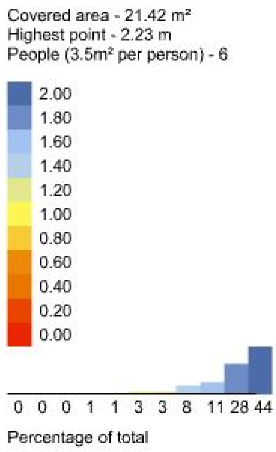


Figure 90 Height stats

- A plan view is drawn that incorporates the data of the heights represented with the coloured scheme at every measurement quad. This can serve multiple purposes, like identifying the parts where a human can pass, the areas that are inefficient for a certain type of activity, and so on. It can serve as a tracing layer for floor planning (Figure 91).

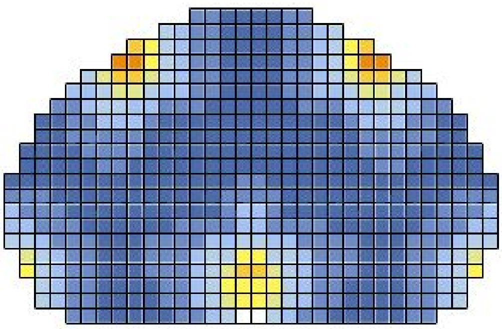


Figure 91 Shelter heights' floor plan diagram

- Lastly, a floor plan diagram is drawn that represents the cover of each membrane piece and shows the areas where the height of the membrane is lower than the given threshold. This threshold can be indicated independently from the height colouring graph (Figure 92).

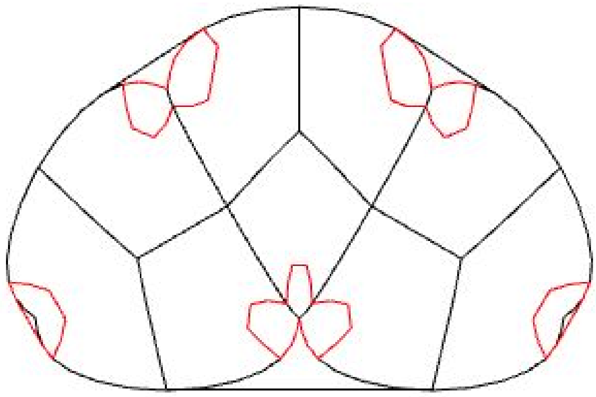


Figure 92 Low height regions

Figure 93 shows the overall look of the design analysis and feedback interface.

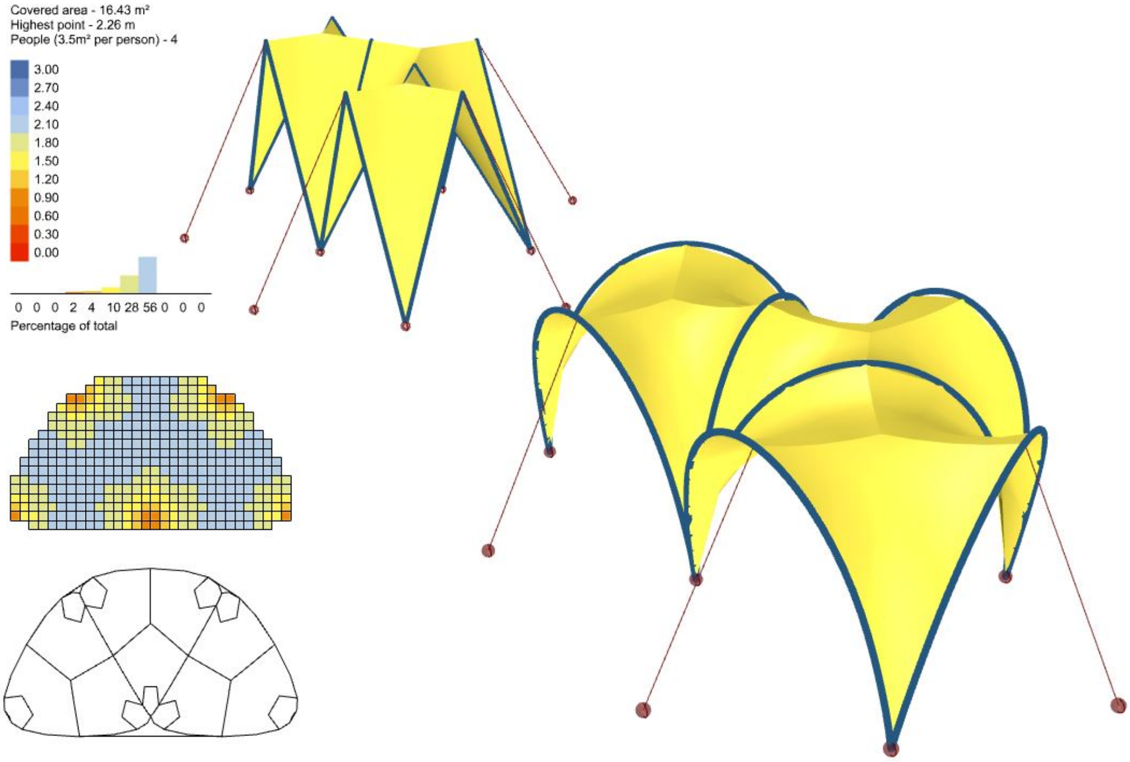


Figure 93 Shelter analysis interface

8.3.7 Discussion

Humanitarian architecture has differences from other domains of architectural design practice. Those particularities should be addressed because they have an impact on the quality of shelter millions of people in need will receive. Emergency shelters often require large deformation analyses to know their final state. In regards to that, computational modelling provides the possibility to create custom made algorithms and tools that aid specific design tasks. By having the shelter design task at hand, the earlier developed algorithm was adopted for shelter design and was used to create study models. Those study design cases show the potential of the algorithm for shelter design. The efficiency of some emergency guidelines is questioned, and a deeper alternative validation method is proposed for compliance to height and area standards for shelters.

8.3.8 Conclusion

An attempt was made to bring cutting-edge architectural design technology to the hands of humanitarian architects to foster shelter design procedures. Algorithmic modelling and physics simulations give the possibility to create tailored design tools that can suit a specific design task. Results obtained in this research propose new methods and demonstrate how to use those methods. Also, this thesis questions the efficiency of some widely accepted standards for humanitarian architecture and proposes an alternative for a detailed analysis of the shelters' internal geometry.

8.3.9 Further work

As it was stated earlier, the algorithm now does not perform structural analyses with real material stiffnesses. This is an important missing part that will be addressed in future research. The proposed heightmap calculation method will be used to evaluate existing popular emergency shelters.

8.4 THERMAL COMFORT OF EMERGENCY SHELTERS

8.4.1 CASE STUDY 1: UNHCR TENT SENSITIVITY

8.4.1.1 OVERVIEW

The aim here is to characterize different factors that affect the internal thermal comfort of the most popular emergency shelters. Parametric numerical models of the emergency tents are created in a visual programming environment together with their energy simulation inputs. In each round of sensitivity check, one parameter is leveraged while retaining others constant for three different climatic zones. The results show that some geometrical parameters have more importance than others and thus may receive more attention from the designers for better output.

8.4.1.2 CONTEXT

For the thermal studies of the tent models, three different climatic zones have been selected. The choice was motivated by the existing locations of some refugee camps and the nearest availability of their weather data.

Table 6 Thermal analysis locations

CAMP NAME	COUNTRY	WEATHER DATA	CLIMATE
Calais Jungle	France	Oostende (Belgium)	Cold, very humid
Moria	Greece	Mytilene	Warm, humid
Am Nabak	Chad	Abeche	Hot, dry

8.4.1.3 STUDY

The first study is thought to be the continuation of the work performed by [34]. The parametric model of the UNHCR family tent is further developed to incorporate the thermal data. The construction material data is added to the model. The main difference from the study done by [34] are that this model is simplified. Instead of having seven thermal zones, we use three main thermal zones. The air gap of the composite is modelled to be a parametrically controlled layer inside the composite of the enclosure. Also, the construction materials are not created as transparent windows materials but opaque construction materials instead. Material characteristics and their allocations are copied from [34].

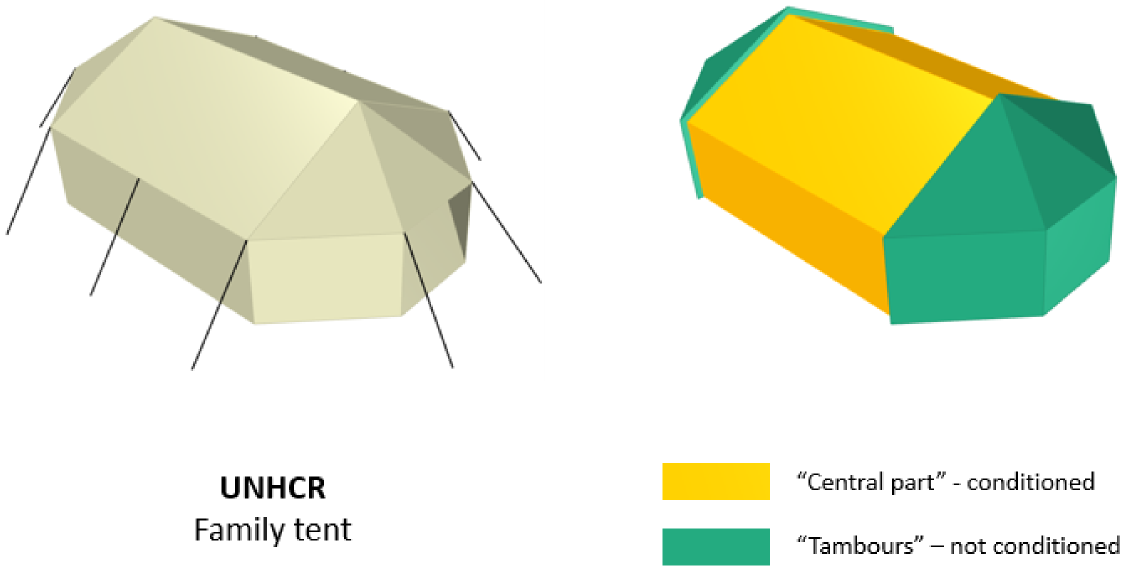


Figure 94 Family tent thermal zones

The analysis duration is chosen to be ten days in October of a typical year. The criteria that were tracked for change was the total energy needed for this period to keep the internal conditions within the comfort range.

8.4.1.4 SENSITIVITY 1 - ORIENTATION OF THE TENT

The first sensitivity test is an attempt to determine whether the tent orientation causes any impact on the total energy need.

Three location and ten steps of rotation increments (0-180) are fed to Collibri as genomes. The tracking phenome is the total energy need.

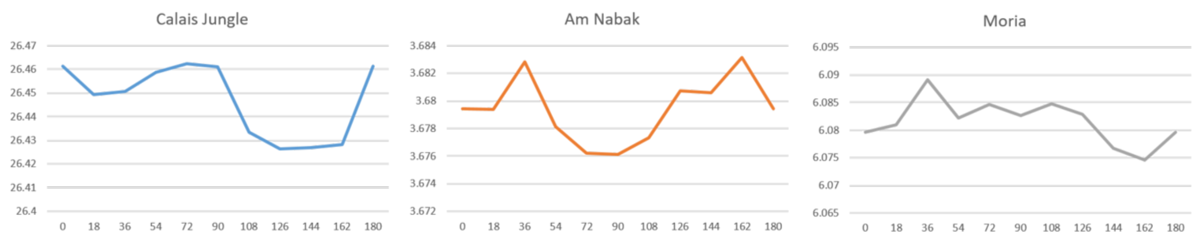


Figure 95 Change in orientation

Energy need (vertical) based on the rotation angle (horizontal)

Given 3 locations and 11 orientations to test: in total, 33 there are genomes.

The resulting 33 simulations show (Figure 95) that although there is some slight difference in the final energy need for one week, the variance is negligible <1%. However, further analysis of longer periods may result in higher variances.

8.4.1.5 SENSITIVITY 2 - WALL HEIGHT

The second sensitivity test is the tracking of the energy needed based on the change of the tent wall heights. Since, in this case, there is a change in the volume of the tent, the need is tracked per unit volume.

The height of the walls is changed from 1 to 2 meters with 0.1m increment. In total, 11 heights.

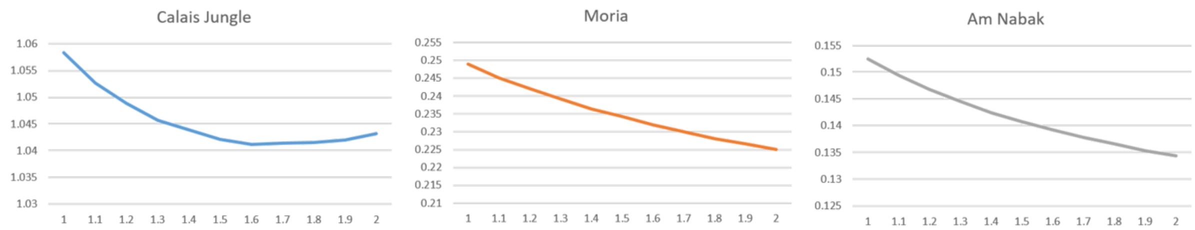


Figure 96 Change in wall height

Energy need (vertical) based on the wall height (horizontal)

Again there are 33 genomes in here. The results show (Figure 96) that the change, in this case, is different based on the location. So the respective variances are 1% for Calais Jungle, 9% for Moria and 12% for Am Nabak.

8.4.1.6 SENSITIVITY 3 - ROOF HEIGHT

The third sensitivity test is the tracking of the energy needed based on the change of the roof height.

As in the previous case, where there was a change in the volume, the energy need is tracked per unit of volume.

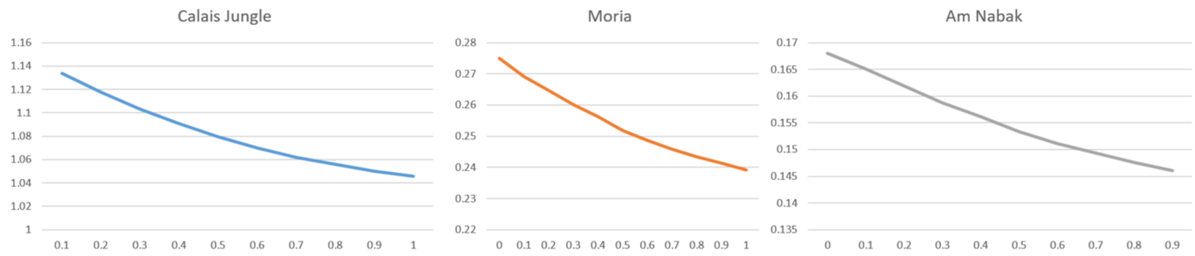


Figure 97 Change in roof pitch

Energy need (vertical) based on the roof height (horizontal)

The roof height is increased from 0 to 1 meter with an increment of 0.1m. So in total, 11 heights and 33 genomes were combined with the locations.

The results show (Figure 97) variances, respectively 7% for Calais Jungle, 10% for Moria and 11% for Am Nabak.

8.4.1.7 SENSITIVITY 4 - VARIABLE AIRGAP

As mentioned earlier, this model was different from the energy model of [34]. Here instead of modelling the air gap as a separate thermal zone, it was modelled inside the composite of the tent fabric as an air-material layer. The sensitivity check in this example was to change the thickness of this layer from 0.1 to 0.2m. This was particularly interesting because the change in the air gap drives no significant change in the tent cost.

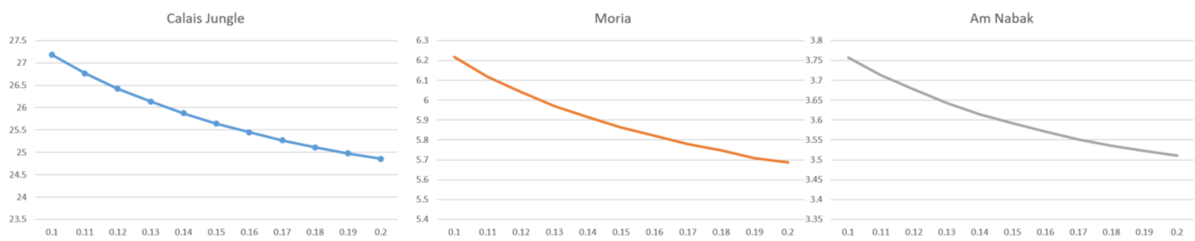


Figure 98 Change in wall air gap depth

Energy need (vertical) based on the air gap thickness (horizontal)

As the results show (Figure 98), there is a slight decrease in energy need. Respectively 6% for Calais Jungle, 8% for Moria and 6% for Am Nabak.

8.4.2 Study N2 - T2 tent optimization for adaptive comfort

The second case study was carried out only for the location of Am Nabak. In this case, the thermal zone of the tent was modelled to be not conditioned. The analysis period is the month of July of a typical year. The tracked value was the percentage of hours where the internal conditions of the tent met the conditions of adaptive comfort.

8.4.2.1 SENSITIVITY CHECK - SHADE NET ANGLE

Here the study aimed to determine the best angle of the openness for the shade net to maximize the adaptive comfort met hours of inside the tent during the hot July.

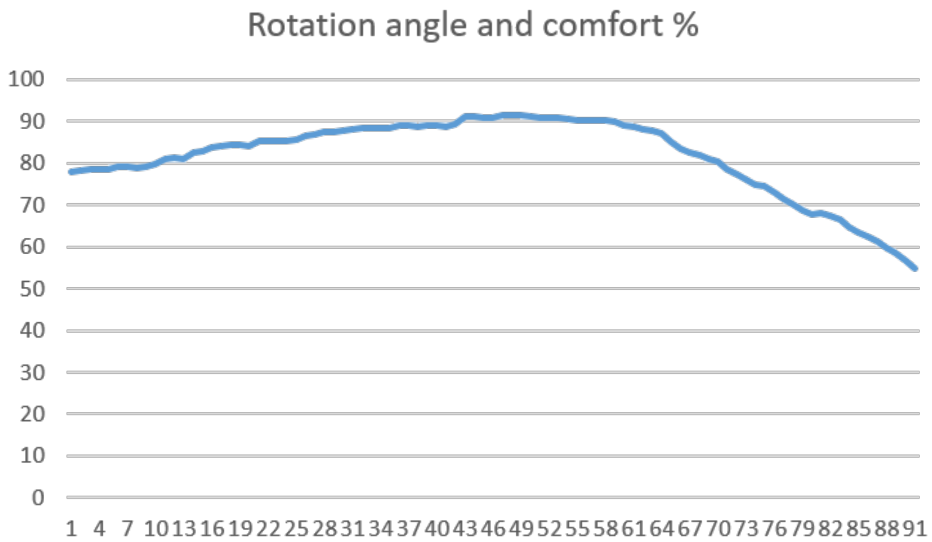


Figure 99 Percentage of comfort hours per shade net opening angles

The shade net opening angle was gradually incremented with the step of 1°. In total, 91 simulations were performed that show us the resulting percentages. As can be seen, if the shade net is opened with an angle around 50°, it will give the best results. (Figure 99)

8.4.2.2 GENETIC OPTIMIZATION - ORIENTATION AND THE OPENING ANGLE

Lastly, a genetic optimization algorithm [60] was incorporated with two degrees of freedom for the orientation of the tent (like in the UNHCR sensitivity test) and the opening angle of the shade net.

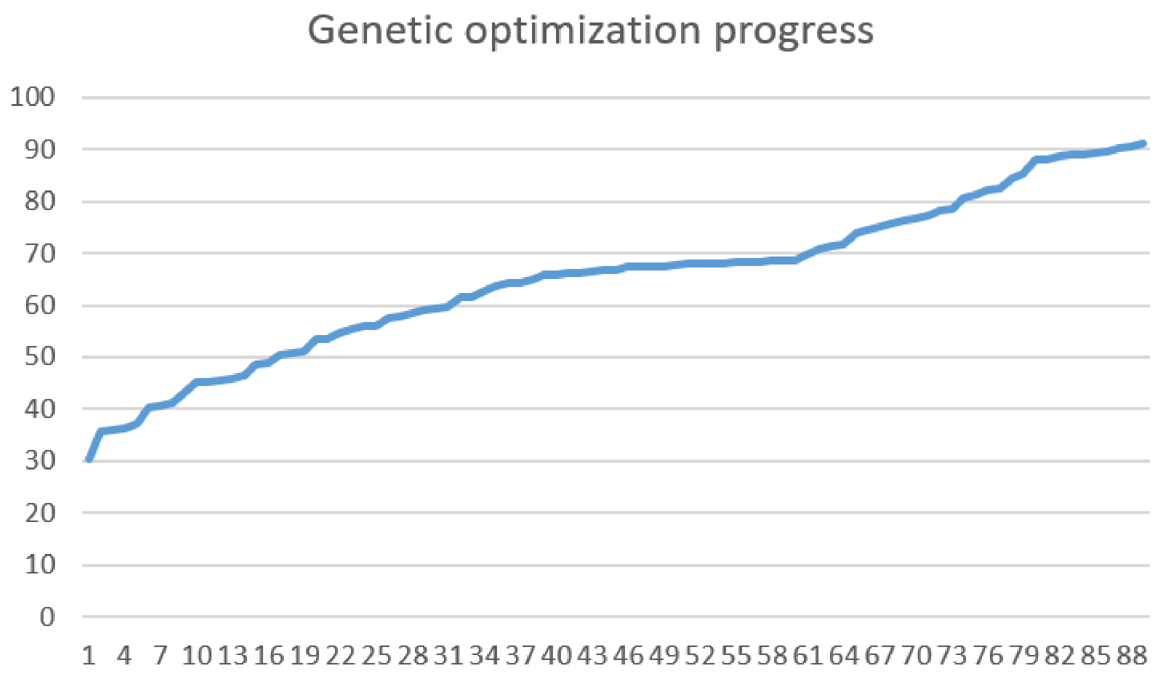


Figure 100 Optimization of the percentage of comfort hours per genome

As shown in Figure 100 and Figure 101, based on these two factors alone, we can have a huge difference in the percentage of hours where the internal conditions are comfortable.

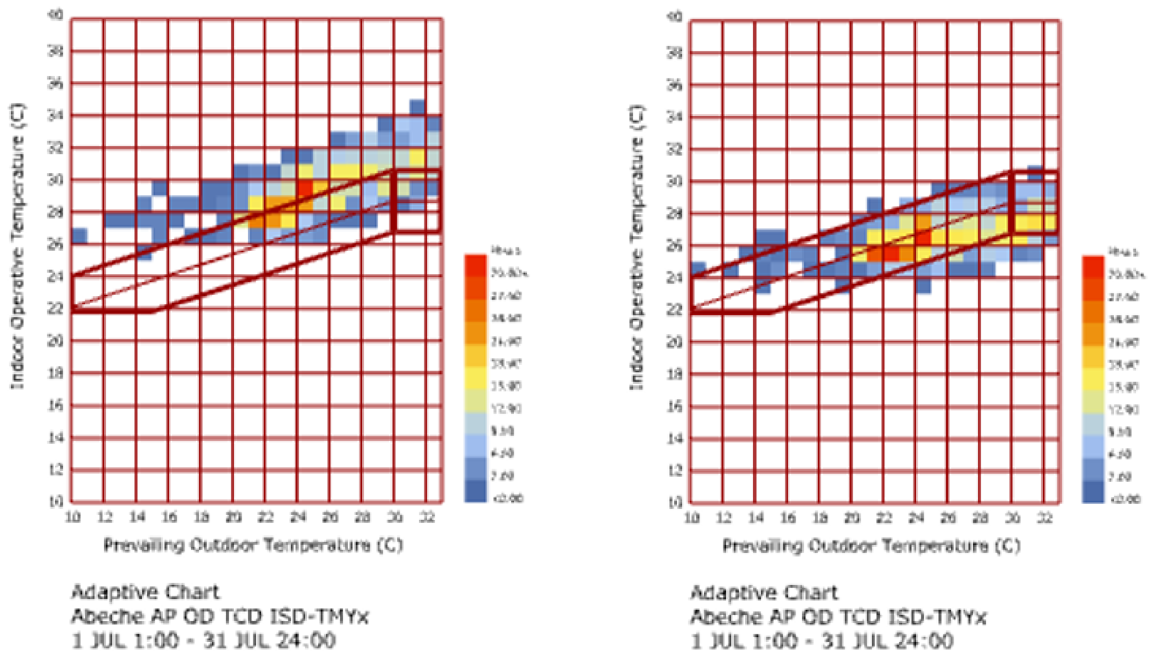


Figure 101 Amount of hours meeting the adaptive comfort demand

9 SUMMARY OF RESULTS

This chapter will summarize all the findings and developments of the research.

9.1 OVERVIEW

There has been a huge amount of work done by many international organisations and NGOs to understand the needs of affected populations when serving humanitarian assistance. This includes the service of settlement and shelter. Despite all the effort, we can see that there is a big shortcoming of how we know things should be and how things are. This is largely attributed to the fact that the collected and allocated money to mediate the atrocious effects on populations always comes shorter than what is needed. In all the cases investigated in this research, there has been no instance of a humanitarian response where 100% of the population received a full package of the necessary aid.

From the literature review, we can see that there have been some attempts to make developments in architectural technology used for humanitarian response, however, given the scale and quantity of disasters and conflicts in the world. Fundamental work is lacking here that will make a big step for integrating the computational methodologies for the use of humanitarian response. Knowing that any developed technology requires some time for adaptation and use, earlier research in this field becomes a necessity.

Nevertheless, the research identified results in other domains that can be reused in humanitarian architecture.

9.2 SETTLEMENT

The research has presented a new methodology for the design and evaluation of refugee camps. The new tools were efficient not only in trial camp planning activities but when applied to existing camps as well. Particularly the evaluations of existing camps of Al-Hol and Zaatari showed some of the pressing problems that people are having there is a structured and quantified order. Identified problems include overdensification, lack of infrastructure and fire safety violations.

New planning tools have been shown in this research that can accelerate the planning procedures giving even greater quality to the layouts. As the planning tools have integrated analysis algorithms, it creates an instant feedback loop with the urban planner and the guiding principles for humanitarian architecture.

Some existing planning methodologies like the grid layout or path planning were adopted in algorithms for efficient execution.

A new recursive division planning method was also developed that generates camp layouts with a fundamentally different approach and qualities.

Having the design and evaluation toolset at hand, a combined workflow is developed that analyses the given landscape, determines suitable areas and populates the camp layout adhering to the established norms.

9.3 SHELTER

As the literature review has shown, there have been some attempts to create computational shelter models. In this thesis, a new generalised framework is developed that allows for faster and more accurate shelter design. The scheme based design methodology incorporates the knowledge in form-finding and structural analysis to be used at the hands of the designer. A qualitative analysis algorithm is also created that can assess the internal comfort of the designed shelter.

Several thermal comfort studies were also carried out for tents. The one parameter alteration based methodology has shown that some of the properties of the tent may have more importance for thermal comfort than the others. The thermal optimisation study has shown that in some scenarios, a better thermal condition may be achieved without any extra cost just by leveraging the existing degrees of freedom that the tent has, like orientation or retractable shades.

10 DISCUSSION

10.1 INTERPRETATIONS: WHAT DO THE RESULTS MEAN?

Knowing that there are many shortcomings in humanitarian response, it becomes evident that more research is needed here. Particularly research and development in settlement and shelter planning. Seeing what conventional architecture has achieved in various sectors, we can see that innovation is not only possible but also there are many studies that can be reused for humanitarian architecture. By taking an existing study of form-active hybrid structures [13] and applying it to tent designs (8.2, 8.3), this thesis further emphasises this possibility.

By applying the assessment tools for refuge camps, it was found that existing camps have many problems which eventually exacerbate the living conditions for people. The norms and guides developed by humanitarian agencies are not arbitrary. They are made to ensure the quality of livelihoods of refugees. Whenever any guide is violated, it will have its implications on how people feel in their settlements. Having the technology presented in this thesis at hand, the planners could firstly know from the beginning that certain issues are at play in their designs and secondly could address them early on in their designs. Shortage of financial resources may be critical; however, poor planning also has a great impact. This thesis does not suggest any ways to gain more monetary support for refugees. It does, however, clearly demonstrate ways of better using the available resources at hand. More efficient planning with the same resources can mean:

- choosing a better site location for a camp
- optimizing the infrastructure layouts
- relocating the shelters within an existing camp to redistribute the densities
- designing better shelters
- paying more attention to important parameters for shelter thermal comfort while compromising others
- playing with no-cost parameters of a shelter on site to ensure the best thermal outcome

The results of this thesis mean that despite the grand effort, humanitarian response for settlement and shelter could and should be better.

10.2 IMPLICATIONS: WHY DO THE RESULTS MATTER?

As seen in the dire conditions of the Moria camp, bad living circumstances can result in direct loos via teenage suicides. This is probably one of the most vivid implications of what poor planning and management can lead to, but any other problem existing in refugee camps will surely affect the people somehow. After all, the main goal of humanitarian response is to help people in need. The affected people quite often may not know all the procedures and technology that bring the results to their well being, but they are the ones that eventually feel on themselves whether any given a choice was a good or bad one. As their lives matter, so should matter everything that humanitarian agencies do, including how refugee camps and shelters are planned and evaluated.

10.3 LIMITATIONS: WHAT CAN'T THE RESULTS TELL US?

The field of humanitarian response is vast and has many interconnected parties that work along. All of the studies in this research were performed strictly from an architectural and urban planning view. Given the interrelated nature of many professions that act in humanitarian response, it is not very obvious if any particular method or tool shown in the research will be beneficial or detrimental for other involved parties. Moreover, because of the lack of information on existing refugee sites, the thesis could not derive any particular problematic patterns that arise in many camps. This kind of pattern could pinpoint some overarching issues that could result in new guides and norms for planning. Nevertheless, since the necessary technology is developed here, the only remaining ingredient is the data about camps. Such data is amply present at the hands of people that manage the camps.

An interview with the head of innovation at UNHCR that was carried out during the research has pointed out a big missing component of this research. That would be the temporal component in refugee camps. The camps may undergo significant changes along with their lifespan, including the change of spatial configuration of the camps and shelters. The time factor was not implemented in this research as it would increase the research domain out of the current scope; however, given the reality, it must be addressed in further studies.

10.4 RECOMMENDATIONS: WHAT PRACTICAL ACTIONS OR SCIENTIFIC STUDIES SHOULD FOLLOW?

The key takeaway for the reader from this thesis is the clear depiction of the technology that can be used to ameliorate the living conditions of refugees. The thesis demonstrated that by applying cutting-edge scientific technology, even with a limited amount of information on refugee camps, big advancements could be made on how camps are planned. By making the data more available and by partnering with research institutions, more research can be done in this area. The most reasonable thing to suggest as a follow-up would be a call to the current practitioners to implement the findings and tools of this thesis.

11 CONCLUSIONS

This chapter will summarise the thesis and lay down the map of further research directions.

11.1 SUMMARY

Humanitarian architecture is a very important domain where the made decisions have an immediate impact on the livelihoods of people that are the end-user of it. The thesis started with the examination of the current practices in humanitarian architecture and gave an overview of this practice within the general humanitarian context. As the two main constituents of humanitarian architecture are settlement and shelter, the thesis framework was constructed in relation to these two major topics. Then in the introductory part, the thesis describes the governing methodology of computational design and algorithms as the key to making progress in this domain.

Further on, the thesis provides a detailed review of the current state of the art in the planning practice of refugee camps and refugee shelters through the prism of computational design. As it was discovered, currently, there is not much research and established practice in the instrumentalization of algorithms for humanitarian architecture.

The adopted methodology for the subsequent developments in the thesis was the coupled work of the architect or the human operator and the set of algorithms that are designed to aid site planners and provide valuable insights about both the existing camps and shelters and the potential new designs.

The first big section of the thesis is about emergency settlements. It is largely based on the existing practice and governing norms defined by the leading humanitarian agencies. The developed frameworks establish a workflow where the different parts of refugee camps are constructed as parametric parts of a large system and work in relation to one another. Starting from the site selection for the camp, the evaluation of terrain and actual planning division and allocation of land to the families up until the design of infrastructure and evaluation of the plan layouts, a set of algorithms deployed that can automate and optimize different phases of the work. In order to demonstrate the capabilities of the developed algorithms, several case studies were conducted on some of the widely discussed refugee camps. As a result of these case studies, several deep insights were gained about these camps (like complience to norms, fire risk, GBV risk).

The second big section of the thesis is about shelters.; here, based on the research of current methodology and practice, the lack of instrumentalization was determined. The lack of adequate tools to design and simulate lightweight structures, which shelters are quite often comprised of, makes it difficult for the designers to implement design decisions and analyze their designs. At first, a form-finding and form analysis framework was constructed that can serve as a shortcut for practitioners through the hard task of form simulation. Several use cases are presented for this scheme driven design framework. Later on, this framework is adopted for the design and analysis of refugee shelters. Here the design framework has also implemented some knowledge about the design task. An analysis algorithm is also developed that can give a deeper understanding of the internal qualities of the designed shelters.

The last chapter in this section concerns the thermal comfort of emergency shelters. Based on the available knowledge, virtual thermal models of some of the widely known shelters were constructed. These thermal models were used to understand the importance of different parameters in the overall thermal performance based on their location and climate. An optimization algorithm was also constructed that can help to choose the best solution out of many possible choices.

11.2 FURTHER RESEARCH

This thesis is one of the earliest attempts to couple two big research domains of computational design and humanitarian architecture. Witnessing the pace by which the computational design methodology is being implemented in the AEC practice, it is very likely that over time humanitarian architecture will shift to this methodology as well. This thesis aims to be a stepping stone.

Over the course of writing this thesis, there were so many aspects of humanitarian architecture that could have been selected for computational workflow development. Therefore the thesis did not seek to give solutions to every single task in humanitarian planning but rather to establish algorithms that can serve as a representative example for similar problems that the planners may have. This was the reason why both the settlement and shelter scales were taken into account. Further research and, in this case, it would be more appropriate to say further research and practice can serve two purposes. Firstly, the implementation of the thesis in the humanitarian architecture practice. This phase has already started, and I hope it will successfully penetrate the industry. Secondly, as it can be seen in many other domains, computational design implementation can lead to projects of buildings and cities that could not have been imagined before in terms of their efficiency and sustainability. Further research in this domain can result in the emergence of qualitatively new settlements for refugees.

12 BIBLIOGRAPHY

[1] D. Guha-Sapir, P. Hoyois, P. Wallemacq, and R. Below, “Annual Disaster Statistical Review 2016 The numbers and trends,” 2016.

[2] “UNHCR Population Statistics - Data - Overview,” 2020. [Online]. Available: http://popstats.unhcr.org/en/overview. [Accessed: 21-Mar-2020].

[3] United Nations OCHA, “Global humanitarian overview 2018,” *UNOCHA*, pp. 1–36, 2018.

[4] A. Sphere, *The Sphere Handbook*, Fourth ed. Geneva, Switzerland: Practical Action Publishing, 2018.

[5] The Sphere Project, “Chapter 4 : Minimum Standards in Shelter, Settlement and Non-Food How to use this chapter,” *Sph. Proj.*, no. Technical Support and Design, 2015.

[6] G. (Australian N. U. of E. C. Evans, “Humanitarian Architecture,” 2014. [Online]. Available: http://www.gevans.org/speeches/speech549.html. [Accessed: 05-Nov-2019].

[7] UNHCR, “Shelter Design Catalogue,” *UNHCR Shelter Settl. Sect.*, 2016.

[8] J. A. (University of S. C. WILLIAMS, “Breaking the Grid,” no. May 2005, 2015.

[9] C. (BBC) Nye, “Children ‘attempting suicide’ at Greek refugee camp - BBC News,” 2018. [Online]. Available: https://www.bbc.com/news/world-europe-45271194. [Accessed: 05-Nov-2019].

[10] “Refugee camps are the ‘cities of tomorrow’, says aid expert,” 2015. [Online]. Available: https://www.dezeen.com/2015/11/23/refugee-camps-cities-of-tomorrow-killian-kleinschmidt-interview-humanitarian-aid-expert/. [Accessed: 05-Mar-2020].

[11] “The Red Cross Society of The Republic of China(Taiwan)--Light in the dark – Red Cross Red Crescent hospital in Camp Azraq.” [Online]. Available: http://www.redcross.org.tw/english/home.jsp?pageno=201402140002&acttype=view&dataserno=201604260001. [Accessed: 22-Mar-2020].

[12] J. Lienhard, “Bending Active Structures,” p. 211, 2014.

[13] A. H. Deleuran, M. Pauly, M. Tamke, I. F. Tinning, and M. R. Thomsen, “Exploratory Topology Modelling of Form-active Hybrid Structures,” in *Procedia Engineering*, 2016, vol. 155, pp. 71–80, doi: 10.1016/j.proeng.2016.08.008.

[14] “Home | CCCM Cluster.” [Online]. Available: https://cccmcluster.org/index.php/. [Accessed: 22-Mar-2020].

[15] T. Corsellis and A. Vitale, “Transitional settlement: displaced populations,” p. 464, 2005.

[16] S. Cluster, “Shelter projects 2011-2012,” *I*, p. 2012, 2012.

[17] S. Cluster, “Shelterprojects_2013-14_Lowres_WEB,” 2014.

[18] S. Cluster, “Shelter projects 2015-2016,” p. 72, 2016.

[19] D. Weinreich and E. Montgomery, “Rethinking Refugee Communities: Planning and Design Toolkit,” *Medium.com*, 2016.

[20] A. Huynh, “EMERGENCY URBANISM,” Seattle, Jun. 2015.

[21] E. Daher and S. Kubicki, “Technologies in the planning of refugees’ camps: A parametric participative framework for spatial camp planning,” *IHTC 2017 - IEEE Canada Int. Humanit. Technol. Conf. 2017*, pp. 207–212, 2017, doi: 10.1109/IHTC.2017.8058189.

[22] E. Daher, S. Kubicki, and G. Halin, “Parametric Process for Shelters and Refugees’ Camps Design,” *Proc. 33rd Int. eCAADe*, vol. 2, no. September, pp. 541–548, 2015.

[23] W. Yeung and J. Harkins, “Digital archi for humanitarian design: A case study of applying digital technologies in post-disaster reconstruction,” *New Front. - Proc. 15th Int. Conf. Comput. Archit. Des. Asia, CAADRIA 2010*, pp. 413–422, 2010.

[24] G. Salvalai, M. Imperadori, D. Scaccabarozzi, and C. Pusceddu, “Thermal performance measurement and application of a multilayer insulator for emergency architecture,” *Appl. Therm. Eng.*, 2015, doi: 10.1016/j.applthermaleng.2015.02.062.

[25] C. Zanelli, Alessandra; Monticelli, Carol; Viscuso, Salvatore; Mazzola, "Parametric design and the manufacturing process of an ultra-lightweight roof system for humanitarian relief contexts," 2013.

[26] B. Forster and M. Marijke, European Design Guide for Tensile Surface Structures. TensiNet, 2004.

[27] N. Stranghöner et al., Prospect for European Guidance for the Structural Design of Tensile Membrane Structures. European Commission, 2016.

[28] A. Zanelli *et al.*, "S(P)EEDKITS RAPID DEPLOYABLE KITS AS SEED FOR SELF-RECOVERY," 2012.

[29] C. A. Setchell, E. J. Argeñal, L. L. Malany, and P. J. Giannone, "Shelter and Settlements," *Humanit. Aid Civ. Prot.*, pp. 257–269, 2018, doi: 10.1017/9781107477261.019.

[30] C. Crawford, P. Manfield, and A. McRobie, "Assessing the thermal performance of an emergency shelter system," *Energy Build.*, vol. 37, no. 5, pp. 471–483, 2005, doi: 10.1016/j.enbuild.2004.09.001.

[31] C. Cornaro, D. Sapori, F. Bucci, M. Pierro, and C. Giammanco, "Thermal performance analysis of an emergency shelter using dynamic building simulation," *Energy Build.*, vol. 88, pp. 122–134, 2015, doi: 10.1016/j.enbuild.2014.11.055.

[32] S. Viscuso and A. Zanelli, "Insulated Membrane Kit for Emergency Shelters: Product Development and Evaluation of Three Different Concepts," *Procedia Eng.*, vol. 155, pp. 342–351, 2016, doi: 10.1016/j.proeng.2016.08.037.

[33] G. Salvalai, M. Imperadori, F. Lumina, E. Mutti, and I. Polese, "Architecture for Refugees, Resilience Shelter Project: A Case Study Using Recycled Skis," *Procedia Eng.*, vol. 180, pp. 1110–1120, 2017, doi: 10.1016/j.proeng.2017.04.271.

[34] S. Obyn, G. Van Moeseke, and V. Virgo, "Thermal performance of shelter modelling: Improvement of temporary structures," *Energy Build.*, vol. 89, pp. 170–182, 2015, doi: 10.1016/j.enbuild.2014.12.035.

[35] U. United Nations High Commissioner for Refugees, “Core relief items catalogue,” no. October, pp. 44–49, 2011.

[36] UNHCR, “Family tent for cold weather with fire retardant,” no. 07283, pp. 24–50, 2014.

[37] D. Piker, “Kangaroo: Form Finding with Computational Physics,” *Archit. Des.*, vol. 83, no. 2, pp. 136–137, Mar. 2013, doi: 10.1002/ad.1569.

[38] Y. Kazerooni *et al.*, “Fires in refugee and displaced persons settlements: The current situation and opportunities to improve fire prevention and control,” *Burns*, vol. 42, no. 5. Elsevier Ltd, pp. 1036–1046, 01-Aug-2016, doi: 10.1016/j.burns.2015.11.008.

[39] B. S. Atiyeh and S. W. A. Gunn, “Refugee camps, fire disasters and burn injuries.,” *Ann. Burns Fire Disasters*, vol. 30, no. 3, pp. 214–217, Sep. 2017.

[40] J. Kennedy, “Site planning: Guidance to reduce the risk of gender-based violence,” 2018.

[41] UNHCR, “Regional Strategic Overview 2020 - 2021. Regional Refugee & Resilience Plan (3RP). In response to Syrian crisis,” 2020.

[42] UNHCR, “Global trends: Forced displacement in 2017,” *Glob. Trends*, no. 25 JUNE 2018, p. 76, 2018.

[43] UNHCR, “Regional Refugee & Resilience Plan 2016-2017 in response to the Syria crisis,” 2015.

[44] B. M. Feilden, *Conservation of historic buildings*. Oxford: Architectural Press, 2003.

[45] M. Misra, “Conservation of Ruins,” *Int. J. Environ. Stud.*, 2009, doi: 10.1080/00207230802586705.

[46] M. Dabaieh, More than Vernacular : vernacular architecture between past tradition and future vision. Lund: Media-Tryck, 2015.

[47] M. P. Murphy and A. Ricks, “Beyond Shelter: Architecture and Human Dignity,” *J. Archit.*, 2013, doi: 10.1080/13602365.2013.767054.

[48] M. Dabaieh, N. N. Makhlouf, and O. M. Hosny, “Rooftop PV retrofitting: A rehabilitation assessment towards nearly zero energy buildings in remote off-grid vernacular settlements in Egypt,” *Sol. Energy*, 2016, doi: 10.1016/j.solener.2015.11.005.

[49] M. Dabaieh, “Participatory action research as a tool in solving desert vernacular architecture problems in the Western Desert of Egypt,” *Action Res.*, 2013, doi: 10.1177/1476750313484504.

[50] M. Dabaieh, “A future for the past of spectacular desert vernacular,” Lund University, 2011.

[51] UNHCR, UNHCR Handbook for emergencies. 2015.

[52] T. Wortmann and B. Tunçer, “Differentiating parametric design: Digital workflows in contemporary architecture and construction,” *Des. Stud.*, vol. 52, pp. 173–197, Sep. 2017, doi: 10.1016/j.destud.2017.05.004.

[53] C. Brandt-Olsen, “Calibrated modelling of form-active structures,” The Technical University of Denmark, 2016.

[54] M. Andriasyan, “An algorithm to draw simulations of dynamic, lightweight structural systems with schemas,” *Proc. TensiNet Symp. 2019*, no. June, 2019, doi: 10.30448/ts2019.3245.52.

[55] A. H. Deleuran, M. Schmeck, G. Quinn, C. Gengnagel, M. Tamke, and M. R. Thomsen, “The Tower: Modelling, Analysis and Construction of Bending Active Tensile Membrane Hybrid Structures,” *Proc. Int. Assoc. Shell Spat. Struct.*, no. August 2015.

[56] P. Ayres, P. Vestartas, and M. Ramsgaard Thomsen, “Enlisting Clustering and Graph-Traversal Methods for Cutting Pattern and Net Topology Design in Pneumatic Hybrids,” in *Humanizing Digital Reality*, Springer Singapore, 2018, pp. 285–294.

[57] UNHCR, “A Handy Guide to UNHCR Emergency Standards and Indicators,” 2000.

[58] UNHCR, “Emergency Shelter Standards,” no. June, pp. 1–21, 2006.

[59] J. Bradatsch, P. Pätzold, C. Saboia De Freitas, R. Scheuermann, J. Monjo, and M. Mollaert, “European Design Guide for Tensile Surface Structures: Chapter 3,” 2004.

[60] D. Rutten, “Galapagos: On the Logic and Limitations of Generic Solvers,” *Archit. Des.*, vol. 83, no. 2, pp. 132–135, Mar. 2013, doi: 10.1002/ad.1568.

13 APPENDICES

13.1 LIST OF INVESTIGATED EMERGENCY RESPONSES

COUNTRY	YEAR	EMERGENCY
Turkey	1970	Earthquake
India	1971	Conflict
Nicaragua	1972	Earthquake
Nicaragua	1972	Earthquake
Honduras	1974	Hurricane
Bangladesh	1975	Conflict
Turkey	1975	Earthquake
Guatemala	1976	Earthquake
Guatemala	1976	Earthquake
Turkey	1976	Earthquake
India	1977	Cyclone
India	1977	Cyclone
Thailand	1979-1980	Conflict
Algeria	1980	Earthquake
Haiti	1982	Hurricane
Tonga	1982	Cyclone
Sudan	1985	Conflict
Azerbaijan	1992	Conflict
Eritrea	1998	Conflict
Honduras	1998	Hurricane
Ingushetia (Russia)	1999	Conflict
India	2001	Earthquake
Afghanistan	2002	Conflict
Afghanistan	2002	Conflict

DRC	2002	Volcano
DRC	2002	Volcano
Eritrea	2004	Conflict
Indonesia	2004	arthquake/Tsunami
Indonesia	2004	arthquake/Tsunami
Sri Lanka	2004	Tsunami
Sudan	2004	Conflict
Sudan	2004	Conflict
Vietnam	2004	Typhoon
Pakistan	2005	Earthquake
Pakistan	2005	Earthquake
Indonesia	2006	Earthquake
Indonesia	2006	Earthquake
Bangladesh	2007	Cyclone
Bangladesh	2007	Cyclone
Kenya	2007	Floods/Conflict
Lebanon	2007	Conflict
Liberia	2007	Conflict
Liberia	2007	Conflict
Mozambique	2007	Cyclone
Mozambique	2007	Cyclone
Nicaragua	2007	Hurricane
Peru	2007	Earthquake
Peru	2007	Earthquake
Peru	2007	Earthquake
Peru	2007	Earthquake
Somalia	2007	Conflict

Somalia	2007	Conflict
Sri Lanka	2007	Conflict
Sri Lanka	2007	Conflict
Uganda	2007	Floods
Bangladesh	2008	Cyclone
China	2008	Earthquake
Georgia	2008	Conflict

13.2 PSEUDOCODES FOR THE AREA DIVISION SEGMENT CREATION

13.2.1 METHOD 1: AREA CENTRE TO CLOSEST EDGE'S MIDPOINT DIVISION

for boundary:

find area centroid **A**

find the closest boundary segment **S** to the centroid **A**

find the midpoint **M** of **S**

find the bounding rectangle of the boundary

draw a line through **A** and **M** that reaches the bounding rectangle

find the overlapping segments of the line with the boundary

if multiple segments emerge:

take the longest segment

split the boundary with the segment

return resulting boundaries

13.2.2 METHOD 2: AREA CENTRE TO THE CLOSEST POINT ON BOUNDARY DIVISION

for boundary:

find area centroid **A**

find the closest point **B** on the boundary to centroid **A**

find the bounding rectangle of the boundary

draw a line through **A** and **B** that reaches the bounding rectangle

find the overlapping segments of the line with the boundary

if multiple segments emerge:

take the longest segment

split the boundary with the segment

return resulting boundaries

13.2.3 Method 3: Longest side midpoint perpendicular division

for boundary:

find the longest segment **L** of the boundary

find the midpoint **M** of **L**

find the bounding rectangle of the boundary

draw a line through **M** that is perpendicular to **L** and reaches the bounding rectangle

find the overlapping segments of the line with the boundary

if multiple segments emerge:

take the longest segment

split the boundary with the segment

return resulting boundaries

13.2.4 Method 4: Longest side midpoint to area centre division

for boundary:

find the longest segment **L** of the boundary find the midpoint **M** of **L**

find area centroid **A**

find the bounding rectangle of the boundary

draw a line through **M** and **A** that reaches the bounding rectangle

find the overlapping segments of the line with the boundary

if multiple segments emerge:

    take the longest segment

split the boundary with the segment

return resulting boundaries

13.3 PSEUDOCODE FOR PIPING NETWORK

pts = WASH distribution points

s = water supply point

c = empty collection

for p in pts:

  find the nearest **p** to **s**

  create a **p**-**s** segment **sg**

  add **sg** to collection **c**

  remove **p** from **pts**

for p in pts:

  for **sg** in **c**:

    find the closest **sg**-**p** pair

    create a new segment **sgn** from **p** to the closest point on **sg**

    add **sgn** to collection **c**

    remove **p** from **pts**

final piping network = **c**

13.4 SET OF CONTROLS FOR PARAMETRIC SHELTER MODELS

GROUP	PARAMETER	UNHCR family tent	UNHCR geodesic tent	T2 tent	Bettershelter	IFRC Finland
Shape	Width	+	+	+	+	+
	Length	+	+	+	+	+
	Width steps	-	-	-	+	-
	Length steps	+	-	+	+	+
	Wall height	+	-	+	+	-
	Roof height	+	-	+	+	-
	Radius	-	+	-	-	+
Framework	Width steps	-	-	-	+	-
	Length steps	-	-	+	+	-
	Thicknesses	-	+	+	+	-
Cables	Positions	+	+	+	-	+
	Anchoring	+	+	+	-	+
Grounding	Pikes	-	-	+	+	-
Shading	Position	-	+	+	-	+
	Dimensions	-	+	+	-	+
Openings	Doors	+	s	+	-	+
	Windows	+	-	+	-	-