POLITECNICO DI MILANO

Dipartimento BEST
Scienza e Tecnologie dell'Ambiente Costruito
Building Environment Science & Technology

DOTTORATO DI RICERCA TEPAC

TECNOLOGIA e PROGETTO DELL'AMBIENTE COSTRUITO
ciclo XXV

Roberto Maffei

SHELTERING IN EMERGENCY: PROCESSES AND PRODUCTS

Textile kit for immediate response

2010-2012

RELATORE e TUTOR: Prof. Alessandra Zanelli

POLITECNICO DI MILANO

Dipartimento BEST
Scienza e Tecnologie dell'Ambiente Costruito
Building Environment Science & Technology

DOTTORATO DI RICERCA TEPAC
TECNOLOGIA E PROGETTO DELL'AMBIENTE COSTRUITO
ciclo XXV

SHELTERING IN EMERGENCY: PROCESSES AND PRODUCTS

Textile kit for immediate response.

Relatore e tutor: Prof.ssa Alessandra Zanelli

Coordinatore del Dottorato : Prof. ssa Anna Mangiarotti

Dottorando: Roberto Maffei

2010-2012

CONTENTS

I LISTS OF TABLES AND FIGURES

PART I

Picture and schemes of this section, if not written differently, are drawn/taken by the author

Picture and schemes of this section are all drawn by the Author

II LIST OF ABBREVIATIONS

ALNAP: Active Learning Network for Accountability and Performance in Humanitarian Action www.alnap.org

BRC: British Red Cross, www.redcross.org.uk

CCCM: Camp coordination and camp management

CENDEP: Centre for Development and Emergency Practice, Oxford Brookes University, architecture.brookes.ac.uk/research/cendep/index.html

COHRE: Centre on Housing Rights and Evictions

CRED: centre of research on the epidemiology of disasters, www.cred.be/

DEC: Disasters Emergency Committee, www.dec.org.uk

DINEPA: Direction Nationale de l'Eau Potable et de l'Assainissement - Haitian Minstry for water and sanitation, www.dinepa.gouv.ht

DP: Displaced population

DRR: Disaster risk reduction

ELRHA: enhancing learning and research for humanitarian assistance, www.elrha.org

EM-DAT: International disaster database, www.emdat.be

GFDRR: Global facility for disaster reduction and recovery. www.gfdrr.org/gfdrr

HIF: Humanitarian innovation found. www.humanitarianinnovation.org

IASC: Inter-Agency Standing Committee, www.humanitarianinfo.org/iasc

ICVA: International Council of Voluntary Agencies

IDP: Internally Displaced Person

IFI: International Finance Institutions

IFRC: International Federation of the Red Cross and Red Crescent Societies, www.ifrc.org

IISD: International institute for sustainable development: www.iisd.org

NFI: Non-food item

NGO: Non-governmental organisation

NLRC: Netherland Red Cross, www.rodekruis.nl

ODI: Overseas development institute, www.odi.org.uk

OECD: Organization for Economy Co-operation and Development, www.oecd.org
OXFAM: Oxford Committee for Famine Relief, www.oxfam.org
SRU: Shelter Research Unit
THS: Temporary Human Settlements
UN: United Nations, www.un.org/
UNDP: United Nations Development Programme, www.undp.org
UNEP: United Nations Environment Programme
UNISDR: United Nation International strategy for disaster risk reduction, www.unisdr.org
UNHCHR: United Nations High Commissioner for Human Rights, www.ohchr.org
UNHCR: United Nations High Commissioner for Refugees, www.unhcr.org
UNOCHA: United Nations Office for the Coordination of Humanitarian Affairs, www.unocha.org
UNU-EHS: United Nations University, Institute for environment and human security www.ehs.unu.edu
UN-HABITAT: United Nations Agency for Human Settlements, www.unhabitat.org
WASH: Water, sanitation and hygiene

III PREFACE AND ACKNOWLEDGEMENTS

This dissertation is the result of three years of research and experiments, however the majority of the knowhow I have collected in this period comes from endless discussions and talks with a large number of people; colleagues, but also friends. These collaborations taught me much more than any book or experiment could. Therefore, I wish to thank Vincent Virgo and Corinne Treherne from SRU and IFRC for their time, advice and experience from the field, Domenico Lombardo from Eurovinil S.p.a., for his time and work in the manufacturing of mock-ups and to remind me what is feasible and what should remain on paper, Frank Merks from Losberger GmbH, who believed in the effectiveness of my ideas but pushed me to go further, Arno Pronk from Technische Universiteit Eindhoven, for his brilliant ideas and positive attitude and Alessandra Zanelli first for the tutoring but also for the "methodology" which goes beyond the research and the tests.

My thanks also go to the whole research team at the Centre of Synergetic Structures of EMPA: Rolf Luchsinger, who endorsed my enthusiasm and turned it into an opportunity, Cédric Galliot for his patience and helpfulness at every moment, even in cases of crazy demands, and Dino Costa, always willing to help me, even in testing a sinking catamaran.

Thanks also to Guglielmo Carra and Paolo Beccarelli, two friends, with whom I have shared my ambition and who will remain as reference points even if our office is now a bit empty.

Morover, thanks to Giuliana for her support, understanding and being my number one fan, always.

Roberto Maffei

0 GENERAL INTRODUCTION

My first introduction to the world of humanitarian relief occurred in autumn 2007 while following a course by Dr. Emilia L. C. Van Egmond, Dr. Peter A. Erkelens and Dr. Jules J. A. Janssen entitled “Building Technologies for Tropical Countries” at the Eindhoven University of Technology, in the Netherlands. At the end of this course I was so enthusiastic about the topic that I decided to continue working on the final assignment and to present it at the poster session of the three-day conference “Innovative Sheltering”[1] organized at the same university a few weeks later. Both the course and the symposium broadened my view of architecture which, until then, had been too related to the “big names” and fancy buildings in architectural magazines.

The study of natural and human hazards showed me the fragility of the human being especially when sheltered in the wrong way. On the other hand, the study of local materials and traditions gave me useful input to mix tradition with innovation and new building technologies. Moreover, “Innovative Sheltering” clearly underlined how the problem of sheltering is not simply a matter of products or technologies over processes. Materials, technologies and products are being developed every year and perform increasingly better to the extent that it is now possible to live in extreme climatic conditions (e.g. in the desert or at the poles) with an acceptable level of comfort. On the other hand, processes linked to the socio-, political, and cultural background of any particular location on the globe are much more fluid and difficult to decipher . As for technologies and products, we tend to design towards standardized and accepted requirements. Conversely, in order to define sheltering processes, an all-encompassing view of the political, economical, and social situation in the affected region is required. And it is clear that this particular knowhow is much more complex and contradictory, and is occasionally also impossible to acquire .

What then was the purpose, as an architect, of undertaking a three-year PhD programme in building technology for sheltering in the event of emergency? It took me

[1] www.innovativeshelter.tue.nl

TARGET OF THE RESEARCH

several months to focus and target my research in the right direction and this effort required a careful balance between the general and specific goals, between the technical and the theoretical part, between my attitude as a designer and what is actually required in the field, weighing up products and processes in the right way. This part, I would say, was the most difficult. Architects and building engineers are used to dealing with certainties, to talking about performance generated by fixed requirements set by clients or construction rules: this is the Western world, based on fixed conditions with established codes and regulations. In the event of an emergency, all these certainties upon which architecture and engineering are based are no longer present. In an emergency no certainties are available: risk can only be foreseen while death, injuries and damage are not recognized in the first few days and, occasionally, not even after several weeks. The humanitarian sector is based on uncertainties and undefined factors and parameters which cannot be quantified. As a consequence, the processes and methods required to react in the right way to a specific emergency cannot always be estimated from the very beginning. Anyway, it is clear how preparedness, together with action in the very first hours after an emergency strikes are both crucial. And to be prepared, processes are much more important than products. That said, having the right methods without the appropriate tools would be equally useless.

TWO THREATS: SELECTION OF TECHNOLOGY AND USE OF AVAILABLE MATERIALS

Two threats slowed down the progress of this dissertation. On the one hand, the application of too-sophisticated technologies might well turn into a drawback due to unskilled end-users and beneficiaries, who might not be ready to gain any advantage from that help. On the other, the study and comparison of existing material and technologies, trying to find new uses or applications to bring them a new function and life, is not always appropriate. As stated in the assumption, it is clear that efficiency of materials and technologies comes from careful study of their application in specific conditions. As a consequence, it is equally clear how difficult it is to find an appropriate reuse for these solutions.

For all of these reasons, this thesis has been divided into two parts, the first related to the processes of sheltering and their issues, the second focussing on the development of one single product that can be applied in specific conditions and can yield its small contribution in the wide world of humanitarian relief. The two parts can be seen as a continuum however I advise the reader to consider them as two separate cores, linked not in a consequential, but in a circular way. For this reason, I also advise the reader not to consider the product designed in the second part as an exhaustive answer to all the issues raised in the first one. Conversely, the product itself does generate further theoretical issues which have been only partially covered in the first part. It is in the tension between the holistic and systemic approach of the theory and the specific characteristics of the product that this thesis finds its purpose.

BALANCE BETWEEN THEORY AND PRACTICE

A balance between theory and practice is the final goal of this dissertation starting from two different assumptions. On the one hand, “theory” seems far removed from the emergency field where, in the very first hours, humanitarian players are asked to choose and decide on strategies that are going to strongly influence progress in the affected area.

How could any theory hope to provide help with such a shortage of time? This is the reason why, on the other hand, the easier and faster solution might be to focus time and effort on developing a fully operational, brand-new perfect tent which would cost one dollar and shelter the whole population within just a few hours. However, this project would be as useless as a big book of theory.

THE PERFECT SHELTER(S)

Indeed, the myth of the "perfect shelter" is something that crops up every time there is a discussion about sheltering. Even if every time a new brand claims to have found the solution, as everyone in the sectors knows, the "perfect shelter" does not exist. Nay, it *can* exist when it takes inspiration from vernacular architecture and is based on local solutions adapted to each location and specific exposure to the context[2]. This means that a perfect shelter cannot be universal, and is unfortunately not applicable by the humanitarian sector which requires speedy, instant solutions. As a result, either a number of "perfect shelters" have to be developed, or a "progressive" approach to allow the implementation of a flexible and adaptable shelter (see Chapter 7).

The rapidly deployable inflatable kit investigated in the second part of this dissertation starts from the assumption that every product can provide its own contribution by responding in the best way to a specific on-site condition. Processes and methods should support the decision to deploy and distribute specific products during a specific phase of the disaster, addressing it to the right users. Moreover, this author thinks that learning from a thorough investigation of a product's characteristics would be the best way to express in theory what has been learnt in practice.

SEVEN TOPICS

Seven different topics are investigated in the first part. The problem of sheltering is, therefore, not presented following the traditional linear structure based on state-of-the-art, methodology, data-collection, results and conclusions. The structure is more circular and approaches the problem, including all the steps of the traditional structure, in an omni-comprehensive way. Disaster relief is not linear and therefore a linear process simply cannot be the correct way to describe a process which is much more complex. Seven topics are investigated starting from basic assumptions taken from literature and are then discussed and presented linked by particular case studies either taken from other sectors such as architecture, design or general engineering, or experiences from NGOs, and elaborated in such a way as to allow the reader to learn and evaluate possible opportunities of "contamination".

INNOVATION THROUGH "CONTAMINATION"

The additional value of this author's architectural background makes its contribution by attempting to give an answer to emergency issues based on the use of standard, well-known and globally available materials such as textiles and films which, thanks to their properties of lightness and the possibility of being processed in every country of the world, might prove effective in providing solutions to the questions raised by theory. Textiles and lightweight construction in general are, therefore, a guiding thread that will link and connect all the topics, in terms of lightness and efficiency, as an effective answer to disasters.

TEXTILES AND LIGHTWEIGHT CONSTRUCTIONS

2 Rapoport A. (1969), *House form and culture Prentice-hall*, Englewood cliffs, US

READERS OF THIS MANUAL

This research has been conceived for three different kinds of reader:

- Firstly, architects, engineers or students who would like to approach the topic of sheltering for emergency in the near future: they will learn how the humanitarian sector differs from the traditional building construction sector and how to deal with it;
- Secondly, people from the field who are already a mine of information but have no time to set all of it on the table in an organized way: they will find inputs from different fields which will, I hope, inspire them and result in innovation in the sector;
- Thirdly, people from private companies who understand little of the world of humanitarian relief but would like to make their contribution by developing "ad hoc" solutions and products: they will come to understand which leverages they need to focus on to achieve their goals.

Each reader will have the possibility to finds his or her own path and, I hope, become inspired to innovate the sector from different points of view.

0.1. Emergency and sheltering

EMERGENCY

DISASTER

Emergency can be defined as any situation of urgent need, or a particular state–especially with a need for help or relief–created by some unexpected event[3] which may be natural or technological (e.g. weather conditions, disease, war...). A disaster is a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources. Though often caused by nature, disasters can have human origins. A disaster occurs when a hazard impacts vulnerable people. The combination of hazards, vulnerability, and inability to reduce the potential negative consequences of risk, results in disaster[4].

HAZARD

Looking at the definition on the international disaster database, a hazard is a threatening event, or the probability of the occurrence of a potentially damaging phenomenon, within a given time period and area[5].

Natural hazards are naturally occurring physical phenomena caused either by rapid- or slow-onset events which can be geophysical (earthquakes, landslides, tsunamis and volcanic activity), hydrological (avalanches and floods), climatological (extreme temperatures, drought and wildfire), meteorological (cyclones and storms/wave surges) or

[3] Oxford dictionary, www.oxforddictionaries.com

[4] *What is a disaster?,* IFRC, www.irfc.org

[5] The international disaster database, Centre for research on the epidemiology of disasters, www.emdat.be

biological (disease epidemics and insect/animal plagues). Technological or man-made hazards (complex emergencies/conflicts, famine, displaced populations, industrial accidents and transport accidents) are events caused by humans and occur in or close to human settlements. These can include environmental degradation, pollution and accidents.[6].

There is a further range of challenges, such as climate change, unplanned urbanization, under-development/poverty as well as the threat of pandemics, which are going to shape humanitarian assistance in the future. These aggravating factors will also result in increased frequency, complexity and severity of disasters[7].

Over the past decade, an average of 250 million people a year have been affected by natural disasters, and these are only the ones we know about. Most disasters go unnoticed, or at least un-investigated. What may be catastrophic to one or two villages in less well-known parts of the world is often overlooked when annual Asian floods or the hurricane seasons bring suffering to millions of people. But all disasters are serious and most are increasing, in number and intensity, the smaller events more rapidly than the larger ones[8].

TREND OF DISASTERS

The number of disasters increased greatly over the last decade and, as shown in the "Annual Disaster Statistical Review 2011" published every year by the Centre for Research on the Epidemiology of Disasters (CRED)[9] considering the last decade, from 2001 till 2011, the average number of disasters reached 384 per year. Unfortunately, 2011 will go down in history as the worst year in terms of economic damage due to natural disaster, with an estimated US$ 366.1 billion. Additionally , natural disasters killed a total of 30,773 people and caused 244.7 million victims worldwide.

0.2. The Sheltering Process

SHELTERING

NGOs and local authorities have to deal with these numbers every year and since the publication in 1982 of the guidelines: "Shelter after disaster: guidelines for assistance"[10], sheltering has became, together with health, food, water and sanitation, one of the major tools to provide an answer to these crises. Sheltering has both primary and secondary objectives. First of all, sheltering has to be considered something much more than merely providing a roof. Sheltering is a process and a basic necessity that meets the following needs:

Health: good quality shelter improves public and individual health by providing protection against rain, snow, wind, dust, sun, cooking smoke and vector-

[6] In July 2008, CRED (Centre for Research on the Epidemiology of Disasters) and MünichRe released a common "Disaster Category Classification for Operational Databases". This new common classification represents a first step in the development of a standardized international classification of disasters.

[7] Type of disasters: definition of hazards, IFRC, www.ifrc.org, see appendix 1

[8] RCRC, *Climate guide 2011*, p 92, available at: http://www.climatecentre.org

[9] The Centre for Research on the Epidemiology of Disasters, CRED, www.cred.be

[10] UNDRO, Davis I., (1982), *Shelter after Disaster: Guidelines for Assistance*, United Nations, New York.

borne diseases. In emergencies, sheltering saves lives through protection from exposure to extreme conditions of heat or cold.

Safety and security: sheltering provides physical protection for people and their possessions.

Psychological support: sheltering provides a sense of ownership and gives families the chance to start again from "something".

Dignity: sheltering creates a private space for individuals and families, allowing them to live with dignity.

Livelihood support: sheltering is both a wealth asset and frequently a site for livelihood activities. Without some form of livelihood strategy people are totally reliant on externally supplied services.

Social support: sheltering reflects emancipation and defines the position of a family in the social hierarchy.

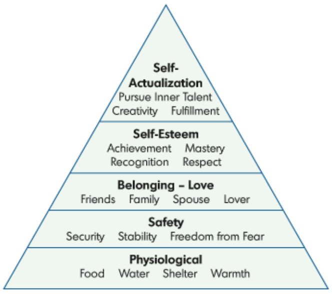


FIG. 0.1: MASHLOW'S HIERARCHY OF NEEDS

Because these needs are considered to be an essential part of human life, people are considered to have a right to basic shelter. The international right to adequate housing is enshrined in the Universal Declaration of Human Rights[11] as well as the International Covenant on Economic, Social and Cultural Rights (ICESCR)[12]. In addition, Sheltering is presented as fundamental in the Maslow pyramid model[13] where it could clearly be entered both at the physiological and the safety level.

Moreover, shelter programmes, which often require considerable quantities of labour and materials, can have significant positive secondary impacts upon both host and beneficiary populations:

Macro-economic impact: shelter construction and procurement can support the local economy or even contribute to economic recovery. The short-term impact of local procurement and employment as part of an emergency response is often crucial when livelihood recovery programmes are not in place. Longer-term shelter reconstruction programmes provide employment opportunities as significant as the actual shelters built.

Capacity building: programmes can develop the shelter and settlement management capabilities of local authorities by working in partnership to meet minimum standards and improve beneficiary participation.

Skill-raising: the skills training opportunities provided by shelter programmes can improve livelihoods and result in safer, more durable shelters.

---

[11] Universal Declaration of Human Rights, available at: www.un.org/en/documents/udhr/index.shtml

[12] International Covenant on Economic, Social and Cultural Rights, available at: http://www2.ohchr.org/english/law/cescr.htm

[13] Maslow, A.H. (1943), *A Theory of Human Motivation*, Psychological Review 50(4): 370-96.

Peace and reconciliation: participation in peace and reconciliation activities can often be leveraged through shelter assistance.

Interaction with other sectors: shelter programmes have two-way relationships with other sectors. Provision of shelter without services, particularly in return programmes, can lead to low occupancy rates.

DO NO HARM PRINCIPLE

Shelter programmes may also have unintended negative consequences. Most of these are identified in the "Do No Harm principle"[14][15]. These unintended consequences should of course be mitigated as far as possible.

Sheltering enters at any stage of an intervention, from preparedness prior to an emergency through immediate emergency response and transitional shelter support through to housing programmes. A shelter rehabilitation programme, for example, may also involve disaster risk reduction through improved, safe building techniques. There are different processes for sheltering according to the phases, variety and local conditions of any specific emergency.

TIMING AND SHELTERING

Temporary (or "emergency") sheltering is normally provided in the first stages of an emergency (typically plastic sheeting and tents) and is defined as having as short a lifespan as possible. A further step, so called semi-permanent (sometimes called "transitional") shelter is a bridge between the emergency and recovery stages, normally defined as having a lifespan of 1-3 years. Transitional shelter is a term most closely linked to natural disaster shelter programmes, where materials can be re-used in permanent reconstruction, but is also used to provide basic housing for return or resettlement programmes for the conflict-displaced which can later be upgraded to permanent housing. The last step of sheltering includes the provision of permanent housing, normally as part of return projects.

THE SOONER, THE BETTER

This dissertation will mainly focus on the application of sheltering in the early stages after a disaster or crisis has occurred, the main reason for this is that sheltering bases its effectiveness on one basic principle: between emergency shelter[16] provision and permanent reconstruction there is a range of intermediate options, however, the earlier the reconstruction process begins, the lower the ultimate social economic and capital costs of the disaster will be.[17]

---

[14] CDA (2004), Do No Harm Handbook.

[15] Anderson M. B., (1999) *Do No Harm: how aid can support peace – or war*, Lynne Rienner Publishers, London

[16] Since 2006 IFRC has assumed a leading role in Emergency Shelter in Natural Disasters. Back in 2006, Emergency shelter was defined as 'the provision of basic and immediate shelter needs necessary to ensure the survival of disaster affected people, including "rapid response solutions" such as tents, insulation materials, other temporary emergency shelter solutions and shelter related non food items'.

[17] UNDRO, Davis I., (1982), *Shelter after Disaster: Guidelines for Assistance*, United Nations, New York.

0.3. The innovation process in building construction

Sheltering is part of the building sector and therefore innovation in this field is strictly linked to the development of construction methods and building technologies. This author's background obliges a remark on innovation and its process in the building sector.

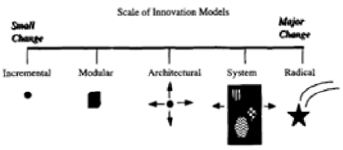


FIG. 0.2: SLAUGHTER'S MODEL OF CONSTRUCTION'S INNOVATION

As presented by Slaughter, five models of construction innovation can be identified[18]: Incremental, Radical, Modular, Architectural or System Innovation.

Incremental and radical are the two ends of the spectrum which measure the magnitude of change compared to the state-of-the-art (figure 0.2). The incremental model comes from small changes based on experience, while the radical model offers a completely new solution previously unavailable. Incremental innovation occurs constantly, while radical cases are rare and unpredictable especially in terms of the unknown consequences they may generate. Incremental innovation generally arises within the industry which possesses knowledge linked to the state-of-the-art. Conversely, radical innovation comes from outside the sector and is often based on research. Modular and architectural innovations deal with the degree of interaction with other components or systems. In the case of modular innovation, the links with other components remain the same while one component significantly changes. The architectural model suggests a minor change in components but major innovations in terms of links and connection to the whole system. System innovation refers to the integration of multiple independent innovations that must coexist to improve performance as a whole.

THE INNOVATION AND BUILDING SECTOR

The building sector is generally considered an outdated field in which innovation rarely arises[19]. Conversely, innovation is transferred slowly from more dynamic and cutting-edge sectors like aerospace, industry, sports and fashion. Innovation surfaces s in the construction sectors years or even decades after the same principle has been exploited in other fields. The reason for this sluggishness depends on various factors. First of all, the construction market has been, traditionally, one of the largest in terms of turnover. Therefore, other fields have been attracted by the sheer volume of that market and tried to enter it by offering solutions developed for other purposes. On the other hand, traditionally, the players who lead the building sectors have not really looked for novelties due to the continuous market growth and high demand for products. Moreover, the building sectors' players are generally resistant to novelty since their knowhow is strictly linked to traditional building construction methods and, as long as business is growing, they see no reason to alter their behaviour.

But things are changing: the economic crises have hit the building sector hard, and it too has to find new ways to be attractive. In recent years, the efforts of the manufacturing

---

[18] Slaughter E. S. (1998), *Models of Construction Innovation, Journal of Construction Engineering and Management*, 124 (2) 226-231.

[19] Sinopoli N., Tatano V., (eds), (2002) Sulle *tracce dell'innovazione: tra tecniche e architettura*, Serie di architettura, FrancoAngeli, Milan

industries to achieve sustainable production have shifted from end-of-pipe solutions to a focus on product lifecycles, integrated environmental strategies, and management systems. Furthermore, efforts are increasingly made to create closed loops and circular production systems, and to adopt new business models. As a result, sustainability and energy-saving building are now part of a wider phenomena called Eco-innovation[20] which is clearly heading in the direction of more environmentally friendly construction methods and technologies which require a profound revision of the traditional view of building architecture. In this respect, lightweight architecture finds its path due to its intrinsic characteristic of using material in the most efficient way, thereby saving material and energy at the same time.

0.3.1 The particular case of lightweight construction

The reason you get better products out of the car industry, aerospace and racing yacht design is because they are all businesses that depend on performance to succeed. In architecture, success does not depend on performance but on value. To get better performance you need a lot of research and development, to get value you need only scarcity[21].

FIG. 0.3: FORD MODEL T

Lightweight constructions differ from traditional architecture in several ways. First of all, their success is strictly related to their performance. Compared to traditional buildings, designed to last fifty or even more years, they are conceived and built to give an answer to a particular and, most of the time, temporary need: sports or leisure events, seasonal activities or emergencies are just some examples of a trend which has been growing over the last few years as clearly described in the literature[22]. The success of these structures is related to their speed of assembly, their success in reducing the duration of the building process, the advantages that derive from a dry-assembly system and to their reduced size in terms of both the volume and weight of the components, which makes construction both easier and safer too.

Secondly, lightweight structures are also synonymous of efficient use of materials[23]. Redundant parts are avoided and prefabrication allows comprehensive control of the building process. The number of elements is reduced to a minimum and this is an extra reason to consider these kinds of structure as a step towards environmental and economical sustainability.

[20] OECD (2009) *Sustainable manufacturing and Eco-innovation, framework, practices and measurements*

[21] In Bookes (2004): Pawley M. (1990) Theory and design in the second machine age, Basil Blackwell Ltd, Oxford

[22] Sarger R. (1967), Kronenburg R. (2000), (2005), Zanelli A. (2003)

[23] Brookes A. J., Poole D., (eds), (2004) *Innovation in architecture,* Spon Press, London, New York.

Thirdly, materials and technologies are applied at their limits, therefore research and development became crucial to achieve the design goals.

Fourthly, lightweight structures are essential by definition, and therefore they have a higher risk of become boring and repetitive compared to traditional architecture. As a consequence, "inventiveness" is fundamental to create an atmosphere which combines modularity with variation, old with new, tradition with innovation.

For all the reasons mentioned above, the process of building lightweight structures is much more open to innovation than the general building sector. The process of producing lightweight structures is closer to that used for products rather than the construction of architecture. Innovation, therefore, plays the same key role it enjoys in industries: materials and technologies can be easily borrowed from other fields such as the automotive or boat industries and must obey markets rules that force them to be constantly updated and developed in line with the latest standards.

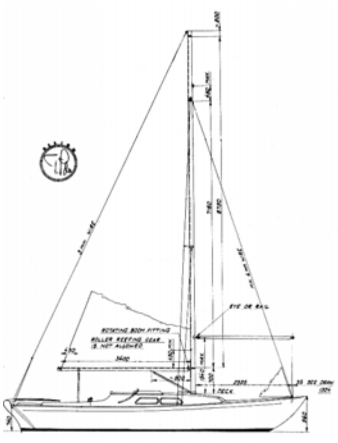


FIG. 0.4: IF-BOAT DRAWINGS

Incisive studies of lightweight technology for architectural applications become the bridge that links innovation from industry and the building sector to the humanitarian one which is traditionally even more resistant to novelty (see Chapter 1). Production and construction methods, together with materials and building systems can be an insightful source of inspiration and, hopefully, can offer solutions to the problem of sheltering in emergencies, too.

0.4 Research assumptions, aims and goals

Assumptions

SHELTERING AS AN EFFECTIVE STRATEGY TO ASSIST VICTIMS

As highlighted in several "shelter and settlement annual reports" by IFRC[24], this research assumes that sheltering is one of the most effective strategies to assist victims and societies affected by a crisis, and can help them return to their original condition of development as agreed several years ago by the main NGOs operating in the field. Sheltering in emergency (at the very beginning after the disaster has occurred) is a crucial phase in which appropriate actions strongly affect the condition and wellbeing of victims in the years to come[25]. This author, in accordance with the scientific and NGO community, believes that sheltering, especially in the very first hours, has room for improvement. The collaborative FP7 project called S(p)eedkits[26], founded by the European Union and focussing on the development of kits to be deployed for immediate response after a disaster, is additional proof of the need for new methods and approaches.

ROOM OF IMPROVEMENTS

Actions and solutions still need further investigation and analysis to find more effective intervention strategies. An innovation process in sheltering is necessary and

[24] IFRC (2011 b), *Shelter department annual report 2010*, Geneva

[25] Sphere project, The (2004), The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response, Geneva, Chapter 4: minimum standards in sheltering, settlement and Non-Food Items

[26] www.speedkits.eu

should first be related to processes and, subsequently, to products. Sheltering solutions have not changed significantly over time due to the fact that the primary role of NGOs is to assist victims instead of investing money in innovation[27]. This is the reason why universities and research institutes should be proactive in research on the topic, as occurred recently thanks to the ANDROID disaster resilience network[28] established in 2012 and ELRHA[29], in 2009. Meanwhile, the Red Cross could take the lead in sharing information and letting academic and industrial partners become involved in the sheltering process, too.

LEARNING FROM LIGHTWEIGHT CONSTRUCTIONS AND TEXTILE MATERIALS

As a response to the need for innovation, the field of lightweight architecture could offer its properties to serve the cause of sheltering in emergency. There are several reasons to consider the lightweight approach as an important step towards sustainable development[30]. Lightweight materials such as textiles, membranes and all materials and components related to the world of fibres feature performance characteristics which are precisely those required in emergencies in terms of resistance, efficiency, usability, and so forth. In addition, the field of textiles is constantly developing and new technologies arise from time to time. As an example, Tensairity® technology[31], an evolution of the well known inflatable system, is promising, and may well give of its best when timing and transportation are crucial.

FIG. 0.5: TENSAIRITY® WING

Aims

INNOVATION IN EMERGENCY: A NEW APPROACH

The aims of this research cover the theoretical and technical aspects of sheltering in emergencies, embracing the problem from both the process and product points of view to highlight possible areas for improvement. Seven general topics, three regarding processes and four regarding products, have been carefully identified and represent the core of the first part of this research. An analysis through topics has been considered with the aim of setting the basis for a new approach to the problem of emergency that would stimulate innovation and the application of processes and products taken from other fields, even those remote from humanitarian relief. Consequently, two general aims can be identified:

- firstly, this research seeks to organize knowledge of innovation in emergency while highlighting weaknesses in the state-of-the-art and the limits of an innovation process based on “internal” resources;
- secondly, it aims to create a link between sheltering for emergency and applications selected from other sectors, in particular, those of lightweight architecture, the textile sector and its related fields. The aim is to present

---

27 Erkelens P.A., Van Egmond E., (2009) *Towards innovative (emergency) sheltering*, SASBE 2009

28 Academic Network for Disaster Resilience to Optimise Educational Development, www.disaster-resilience.net

29 ELRHA, Enhancing learning & research for humanitarian assistance

30 Berger H. (1996) *Light Structures - Structures of Light: The Art and Engineering of Tensile Architecture,* Birkhauser Verlag, Base

31 Luchsinger R.H., Pedretti, A., Steingruber, P. & Pedretti, M.: *The new structural concept Tensairity®: Basic Principles,* in Progress in Structural Engineering, Mechanics and Computation, ed. A. Zingoni, A.A. Balkema Publishers, London, 2004

examples as references to stimulate innovation, to learn from different approaches, and, as a result, to transfer knowledge in terms of technologies but also of the "process" of innovation towards the development of the sheltering sector.

In the second part of the dissertation, a specific product has been selected and developed from sketches to a 1:1 scale prototype to provide an example of interaction between processes and products and to investigate just how complex it is to embrace the whole path, from theory to practice, following the innovative process identified in Part 1.

Goals of the research

To avoid any misunderstanding, a clear distinction of the goals of this dissertation must be made. Two concepts might generate incomprehension. On the one hand, this research will be dealing with the general problem of the *innovation process*, trying to discover potential strategies to renovate the humanitarian sector, and how the readers identified above should approach it in order to achieve something . On the other, this author aims to innovate sheltering that involves *processes* and *products* at the same time. *Innovation of the sheltering process*, therefore, is the second objective of this research which can only be achieved by having the first one clear. A third level focuses on those *products* which are useful tools to alleviate victims' distress. The first, second and third goals are presented in Part 1. The *product development* of a specific example is the fourth goal, presented in Part 2. The following paragraphs will present these in more detail.

The innovation process

THE PROCESS THAT BRINGS INNOVATION

The sheltering process does not just begin when a disaster strikes and does not only include that preparedness which should exist throughout the year, especially in the most vulnerable areas of the planet. The sheltering process should also include all those actions taken far from the field, which exist to set the basis for the next sheltering campaign. Innovation in sheltering cannot be done in the field, but should be thought through, tested, and channelled previously, far from the shortage of time of a crisis. At the moment, the innovation process in the humanitarian sector is slow and, in most cases, futile. The aim of this research, and especially of Chapter one, is, therefore, to spotlight how the innovation process works and the possibility to progress, by combining the approaches and knowhow of universities, NGOs and industry in a systematic way. As a consequence, this thesis will apply this approach to try to innovate sheltering from both the process and product point of view, as presented below.

The sheltering process

It is known worldwide that meeting shelter needs after disasters should be seen as a process of "sheltering" consisting in assistance provided to affected households for the repair or reconstruction of their dwellings or settlements[32]. Assistance can be provided through different materials, and/or technical, financial and social support. The different needs of affected households for safety, privacy, protection from the climate, and maintenance of their livelihoods must be addressed in accordance with the context and available resources. Sheltering solutions must also enable households to improve their homes with the passage of time as resources and opportunities permit. As a result, inflexible solutions that do not lend themselves to incremental change over time should be avoided if and when possible. In this respect, it is clear that sheltering goes beyond the immediate provision of basic shelter solutions and is intimately associated with longer-term reconstruction as well as with assisting individuals, families and communities to re-establish themselves and allow a return of individual dignity. As a consequence, the general aim of the thesis is to adopt a broad outlook that embraces both the very first phase and the opportunity to turn initial help into a process of development[33].

INNOVATIVE PROCESSES OF SHELTERING: FROM THE FIRST PHASE TO DEVELOPMENT

Sheltering is a typical example of a complex problem in which not only technological but also political, socio-economical, cultural, and climatic issues merge into one. In several studies which have addressed the problem, the main focus of sheltering was ignored. The ultimate goal of sheltering is to offer victims a safe, dignified, healthy dwelling in order to support their life and family in a return to their original lifestyle before the crisis. The goal of this research is, therefore, to improve the overall quality of life of an affected population through the study and application of strategies and products which would contribute to improving victims' conditions. Optimum logistics, smart packaging, efficient tents and so on are only tools to support rescue, relief and development processes: it would be a grave mistake to consider these as the goals of this research. Conversely, they must all be considered and be part of a systematic approach to combine victims' needs and NGO and local authorities' capabilities with the latest technological development. It is clear that sheltering is an open process subject to endless debates and therefore, this thesis focuses on three topics to try to provide an answer to at least some of the main issues involved.

IMPROVE VICTIMS' CONDITIONS

The macro areas may be identified as follows:

1) risk and the complexity of introducing innovations and their application in the event of an emergency (Chapter 1);
2) correct identification of targets and the implementation to be fulfilled in order to be successful (Chapter 2);
3) correct estimation of timing and emergency phases for an effective intervention (Chapter 7);

[32] Sphere project, The (2004), The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response, Geneva, Chapter 4: minimum standards in sheltering, settlement and Non-Food Items
[33] UNHCR (2007) *Handbook for Emergencies*, Third Edition, page 44, "Durable solutions".

The tools of sheltering: products

PRODUCT SPECIFICATION

Sheltering process cannot be successful without appropriate tools or products. The latest developments in material science and building technology–but also consideration of experience applied in other fields such as sports or leisure activities–offer a new range of solutions which could well contribute during the emergency phase. There are now hundreds of sheltering products available on the market and even if their performance and layout are consistent, most of them are not (and, I would add, never will be) applied in emergency situations. The reasons for this are several and complex, and involve not only technical performance but mainly cultural, political and economical factors. Moreover, any products, before being applied in an emergency, need to be designed in such a way that they take into account the end-users, performance, and usability with a close look in terms of cost, not only at the single product, but also at the impact each would generate when deployed.
To better investigate these aspects, four topics are presented in Part 1:

4) Lightness and simplicity, as the ultimate goal of every innovation in the field (Chapter 3);
5) Adaptability and modularity as design concepts for the new products (Chapter 4);
6) Low- and high-tech building technologies (Chapter 5);
7) “All in one” vs. “Kit” strategies (Chapter 6)

Product development

CASE STUDY

The goals of the second part of the research entail a closer look at the specific nature of each single product. First of all, starting from the background highlighted in the first part, the research aims to identify those technologies that could be applied in specific cases. Lightweight technologies, together with textile materials play an important role due to their intrinsic characteristics which are precisely those demanded when there is a shortage of time and money. A design methodology based on lightweight structures to be applied in an emergency is also investigated. After a series of preliminary tests to verify the effectiveness of the application of such kinds of systems on emergency occasions, a more detailed investigation into the structural behaviour and, briefly, the comfort provided by a new shelter concept is presented. To conclude, a detailed layout and blueprints for an innovative rapidly deployable sheltering system is defined and, in parallel, a full scale prototype is set up and tested. The kit developed is intended to provide immediate support both to victims and NGOs with their volunteers during the firsts days after an emergency has occurred.

0.5 Fields of application and beneficiaries

The two parts of this dissertation deal with different fields of application and beneficiaries.

The results of the theoretical part of the research are primarily considered to have an influence on and an application in an emergency, especially in disaster relief. In general, the results aim to be useful for any cases in which the sheltering process is to be applied: from preparedness to the relief, recovery and development phases. In particular, the application of this thesis aims to leverage the NGO way of approaching the innovation process in sheltering a long time before an emergency actually begins. A new sheltering process is proposed based on a collaboration between NGOs, universities and the industrial sector. In this scenario, the role of the academia is to act as a link between the demands of the affected population (from NGOs' experience in the field) and available responses in terms of technologies (offered by industry) brought together thanks to universities' expertise in dealing with multi-disciplinarity and complex problems. The examples presented in this section are listed as references which aim to stimulate the creativity of the "insiders" and, at the same time, convince them to involve new players in the innovation process.

HUMANITARIAN SECTOR

The results of the product development part, conversely, could have different applications, even ones remote from emergency situations. The processes and products resulting from the second part give of their best in all circumstances in which time and weight are crucial variables for the success of an intervention. Natural or human disasters are certainly the main applications but, from this perspective, different kinds of "emergency" occur every day which demand a rapid, simple and effective sheltering process. Every event which is temporary and extraordinary, including exhibitions, fairs or sports meetings could derive inspiration and benefit from this investigation and its results. Above all, wind-load resistance, which is frequently critical in lightweight and inflatable constructions due to their intrinsic characteristics, will be investigated in depth.

APPLICATIONS IN OTHER SECTORS

There are two main fields of application which the results of the second part of the thesis inspired: the first is those sports activities that explore the most dangerous and inaccessible places on earth such as deserts, tropical forests or high mountains in which shelters to support human beings need to be advanced and lightweight, and offer high standards in response to the harsh climatic conditions. The second application would be to support lives in the same extreme conditions but in work situations. The oil industry, but also scientific centres which study animals or natural phenomena in remote areas, require high performance dwellings to resist extreme conditions for a limited period of time. Container-like solutions are the norm, but in cases where transportation is an issue, lightweight and compact solutions could prove much more effective.

SPORTS & LEISURE

INFRASTRUCTURES IN REMOTE AREAS

This thesis has been designed and written for four different beneficiaries. The first (and most difficult to reach) addressees of this thesis are NGO practitioners who lead and define the sheltering process. The goal of this dissertation is to present them with the possibility of innovation in sheltering, learning from more advanced sectors and showing the benefits that new approaches would have on both an affected population–by improving their living standards in the development phase–and on the volunteer community, offering them appropriate, efficient tools to carry out their tasks.

NGO PRACTITIONERS

Even though it is clear that NGOs, especially over the last few decades, are open to innovation, the process of accepting any change still seems too slow and complex. The reasons are extensive of course, and are always end-user oriented, and this is a conservative approach which guarantees the aptness of each choice and prevents secondary interests. On the other hand, it is undeniable that room for improvement does exist.

ARCHITECTS AND ENGINEERS

Secondly, this research aims to reach architects and engineers which would like to approach the topic of designing for emergency from a practical point of view. These categories would benefit from reading this thesis in view of the fact that it summarises all the main issues under debate in recent years and gives standpoints and input for further reading. Architects and engineers are advised to change their perspective if they wish to play an active role in this field which features much more complexity and many more problems than solutions.

ACADEMIA

Thirdly, this thesis has been designed for academia, from students to researchers who would like to approach the problem of sheltering from a scientific point of view. They too must approach the topic in the correct way and this is not so easy due to the interminable debates on the topic and the lack of communication from "insiders". The dissertation also wishes to balance theoretical and practical approaches which are usually too biased towards the former in the academic world. An emergency requires clear and simple solutions based on a scientific approach that victims can rely on. An emergency is not a field in which research can be tested out on the shoulders of an affected population. Therefore, everything introduced in the field should have already reached a level of development that makes it safe, wide-reaching and, at the same time, efficient. Any errors cost human lives, and this explains why NGOs are so careful when it comes to introducing novelties in the sheltering process.

INDUSTRY

Fourthly, this research is meant for those third parties in industry and the product development sector who would be interested in offering their expertise in such a sensitive field but do not know how to approach it. They usually blame NGOs for not sharing their information or experience which is sometimes the case for businesses involved in humanitarian processes. But other ways are possible including the ones highlighted in this dissertation, based on a collaborative approach in which expertise is shared from all sides among different players to generate a win-win situation.

0.6 Relevance and innovativeness of the research

Relevance of the research

The results of this research are relevant for both the social and scientific communities, according to the different goals considered.

SOME NUMBERS

From the social point of view, this research aims to support victims, communities, but also volunteers in the application and development of a better sheltering process. The number of victims in natural and human disasters is appalling : according to the Annual

Disaster Statistical Review 2011[34] published by EM-DAT, while the average of annual disasters over the last few decades numbers around 384. In 2011 alone, the impact on affected populations reached the maximum level ever seen: natural disasters killed a total of 30,773 people and caused 244.7 million victims worldwide. Economic damage from natural disasters was the highest ever recorded, with an estimated US$ 366.1 billion. The sheltering process plays an important role on these occasions which, especially in Asia or Oceania, are sadly quite common. It is clear that an effective sheltering process would strongly benefit local economies and, as a consequence, the whole community affected by the crisis. Millions of people worldwide, from different countries and cultures, are being sheltered every year, pleading for health, safety, dignity, and the hope of returning as soon as possible to everyday life. This research keeps these people in mind.

LOGISTICS

From logistical (packaging, stocking and shipment), technological and scientific points of view, the application of promising lightweight construction systems have been investigated in detail. As a result, a clear and better range of applications can be defined. Design and construction methods for these kinds of structures will also be investigated. The logistics and setting-up phase in the field have also been taken into account. More specific studies on the internal comfort control of membrane structures are also mentioned.

IMPORTANCE OF THE FIRST HOURS

The reason for applying these kinds of system on post-disaster occasions comes from a simple consideration: data from humanitarian agencies[35],[36] which shows that the first phase of the emergency is the most critical not only because people die but also because it sets the basis for future development of the affected area and its economy. Therefore, the better the first hours are handled, the higher the chances are of improving victims' living conditions, and shortening their critical circumstances. This is the reason why the process and the products suggested in the second part of this thesis will focus on support for humanitarian organisations as a strategic process that aims to save time and energy to be better dedicated to defining and organising a superior development plan for affected areas.

Innovativeness

INNOVATION: A SHIFT FROM THE TRADITIONAL APPROACHES

From a general point of view, the research aims to be innovative for two different reasons. First of all, it tries to trace a path towards innovation in the complex field of emergency by learning from the latest experiences and ongoing collaborative projects and relate these to the building construction sector. Secondly, it develops a solution which combines the advantages of shelter processes which are currently considered contradictory. Let's analyse those two macro areas in depth.

First of all, it must be clarified that innovation in sheltering is a process of contamination that only began in the last few decades. The literature produced by the most eminent parties operating in the fields shows how the direction in terms of innovation has

---

[34] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

[35] Baird M. E., (2010) Phases of Emergency Management, University of Memphis

[36] David A. (2002). Principles of Emergency Planning and Management. Oxford: Oxford University Press.

been clearly mapped out. Projects like "Sphere"[37] or S(p)eedkits[38], or centres like SRU[39] have been set up to put into practice what has been debated and discussed "internally" for several years.

In any event , the latest changes in the global scenario such as climate change, the shifting of populations from dangerous areas (e.g. coastal areas[40]), the growing of numbers of disasters, the increase in their intensity, the risk related to uncontrolled urbanization (since 2007 the population living in cities is higher than that living in rural areas[41]) but also the energy and sustainability debate, are valuable reasons to speed up this innovation process. In this author's opinion, a shift can be made only by looking and learning from other sectors. The opportunities and advantages of this attitude will be highlighted.

COMBINATION OF APPROACHES

The innovative character of the design developed in the second part of the research relies on a combination of the "kit" and "ready-to-use" approach which are usually considered at odds. The result is a rapidly deployable shelter: this system can be erected in a few hours, with no need for foundations or particular technical skills. The type, material and construction systems will contribute to achieving the best possible solution. The novelty of the results consists in the sustainability of the project itself. Lightweight technology has been applied, being considered a great challenge for architects and engineers and an important step towards sustainable architecture. In fact, materials are used in the most efficient ways and this is what the construction industry should be looking at in order to best use the scarce resources of our planet in the face of continuous population growth as well as urbanization. As a matter of fact, the approach focuses on the first hours after the disaster and suggests that refugees could be hosted in a large span shelter while a better reconstruction plan is being defined. Once people have been moved to other dwellings, (transitional or otherwise) the fast deployable shelter can be used as general support (hosting volunteers, vulnerable people, hospitals, logistic centres). Subsequently, when the first phase of the emergency is over, the shelter can be dismantled and reused in another location.

The whole system is designed to be implementable so that it can be set up in different ways according to specific requirements and availability of material, time and money. This is a completely new approach which tries to combine the efficiency and speed of the "ready-to-use" solution, and the flexibility in use and incremental improvements provided by the kit approach. In this way, the resources made available by NGOs, local authorities, but also local people, can be used in a flexible way according to the specific nature of the occasion: starting from an essential configuration, a certain number of shelters can be provided.

---

[37] Sphere project, The (2004), *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response*, Geneva.

[38] www.speedkits.eu

[39] Shelter Research Unit, Luxembourg, founded in 2009

[40] Goudarzi S. (2006), *Flocking to the Coast: World's Population Migrating into Danger.* In Live Science: Environment.

[41] UNPD (2008), *World Urbanization Prospects: the 2007 revision*, New York.

According to the availability of the moment, time and personnel, these structures can be implemented through additional elements which improve their general performance in terms of usability, load-bearing capacity, thermal comfort and so on. Most of the additional elements s are expected to be found locally.

0.7 Structure of the thesis

This thesis has been designed in the form of a booklet to be easily readable and accessible by different users.

At the beginning of each chapter, readers can find a short abstract which highlights the topic of the subsequent pages. Reading the abstracts will save readers time to find the information required and will help to follow the structure of the dissertation without reading the whole booklet. Standard publications on shelter centres and "handouts" on structures published by the IFRC, UN or OCHA have been taken as a source of inspiration due to their effective communication.

Paragraphs are identified by keywords which are clearly defined both in the text and in the glossary. Sheltering is a worldwide programme which involves and includes all countries right across the world together with their own customs and cultural and historical backgrounds. To be effective in such a complex context, a common and widely accepted platform of common understanding and effective communication needs to be built based on shared basic principles and common vocabulary.

Adopting the right vocabulary is a crucial starting point to understanding and operating in the emergency field and to be sure to achieve the points established by the international community operating in such a context. The vocabulary adopted in humanitarian affairs is intended to be used by people from different backgrounds and therefore it often differs from the technical one used by industry or the theoretical one used by academia. If this thesis is the first approach to the topic, please go through these definitions before proceeding and, in case of doubt, refer to the sections References and Further Reading.

The booklet is clearly divided into two parts: the first, more theoretical, contains seven different essays. The guiding thread linking all the topics is highlighted in the Introduction and in the Conclusion. Each topic is approached and presented following a clear structure which passes through an analysis of the general principles, identifies the issues and contradictions which arise from the state-of-the-art, presents a discussion of the topic through examples, literature and case studies, and suggests methods and highlights areas where the humanitarian sectors could learn something.

The second part presents the product development process for a rapid deployment inflatable kit as carried out by this author during the last year of this research. The structure of this part follows the steps of the product development process: strategy, creation, testing and development, realization[42]. The strategy phase is based on the analysis and conclusion of Part 1 of this dissertation and presents the scope of the product development and its requirements. The creation phase shows the initial ideas, concepts, and home-made prototypes used to come up with an effective solution. The testing and development phase present a selection of the results of the investigations from architectonic, structural and thermal points of view. Product development in terms of production and manufacturing is also presented in this part. The realization phase, which is incomplete at the moment of publishing this thesis, highlights further steps of development and opportunities to take into account in the event of launching the product on the market.

Drawings, sketches, schemes, blueprints, and test data are attached to this booklet in the form of annexes. Please refer to the table of contents for further information.

[42] Lichtenberg, J.J.N.(2005), *Slimbouwen®, a strategy for product development,* Proceedings of the ARCOM Conference 2005, London.

P1 PART 1 INNOVATION IN SHELTERING

INTRODUCTION

> *It is evident that, in the past decade, the understanding of disasters and their consequences has improved. In the face of the mounting social and economic costs of natural disasters in the third world, the international community (donors and recipients of aid alike) have made considerable efforts to improve the quality of disaster relief, preparedness and prevention, to improve our understanding of natural hazards, to estimate the risks resulting thereof more accurately and to take adequate precautionary or preventive measures ahead of disasters. Progress has, nevertheless, been slow: rapid population growth and uncontrolled urbanization degradation of the environment, economic recession and poorly co-ordinated development planning have together conspired to outstrip progress in the control of disasters. It is certain that disasters are not merely "acts of God" but acts aggravated by human error and lack of foresight for which disaster relief can be made ever more effective through systematized planning and management, and that pre-disaster planning does at least help to reduce some of the harshest facts of disasters. Therefore, whatever the difficulties, efforts to improve disaster relief and pre-disaster planning must continue unabated.*[1]

This passage was written thirty years ago by UNDRO, the United Nation Disaster Relief Organisation[2] but it could have been published yesterday. NGOs have given of their best since they began their activities, trying to apply the best process and tools to support disaster victims. For this reason, when looking into humanitarian relief, one would expect to find application of the latest technological developments in such a crucial activity which saves human lives and influences the development of entire regions affected by crises for long periods. But this is definitely not the case. Why? The answer is much more complex

[1] UNDRO, Davis I., (1982), *Shelter after disaster: guidelines for assistance*, United Nations, New York

[2] Now substituted by UNOCHA: Office for the Coordination of Humanitarian Affairs

than the question. This author decided to answer this question through analysis of the seven topics which will be discussed in the following chapters.

Recent facts

HAITI

This research began in January 2010. Only 12 days later, an earthquake of magnitude 7.0 occurred in Haiti, 25 kilometres from Port-au-Prince, killing more than 230,000 people[3], while 300,000 people were injured and around one million people were left homeless. It has been calculated that in total, around 3.9 million people were affected by the disaster.

FIG. 0.6: HAITI EARTHQUAKE DAMAGES

Three years later, Haiti still had not recovered from the shock due to a continuing number of smaller crises as direct or indirect consequences of the original one in January 2010: as only one example, cholera struck the population one year later and is still propagating[4].

In the face of one of the most extraordinary crises of recent years due to the vulnerability of a poverty-stricken country, this was a destabilizing way to start research into sheltering. Haiti attracted the attention of the global humanitarian community due to the scale of the disaster but it has to be admitted that this kind of crisis is exceptional while a huge number of smaller crises affects populations every day of which we know nothing. The example of Haiti is always brought up nowadays and is viewed as an extreme and definitive scenario which set goals that, hopefully, the international community will not have to deal with again for another twenty years. Political, cultural, logistic, and climatic issues all came together, and it is a general feeling among NGOs and local authorities that the national and international communities were not prepared to tackle this crisis either from a process or technological point of view.

JAPAN

Only one year later, on March 11, 2011, an earthquake occurred in Japan in the neighbourhood of Sendai and Tōhoku. It was the seventh strongest earthquake ever recorded, with a magnitude of 9.0, and it killed 19,975 people. The Tōhoku earthquake and the subsequent tsunami in Japan cost US$ 210.0 billion, or 57.4% of globally reported damage as recorded by CRED[5].

FIG. 0.7: JAPAN TSUNAMI DAMAGES

Over the following two years, the country, with help from around the world, invested heavily in the area to try to bring everyday life back to normal. Major problems that arose involved–in parallel with the nuclear emergency now listed as being as severe as Chernobyl–the movement of debts, land issues, and property rights. Reconstruction is still hotly debated above all since some think it may be time to abandon the towns and villages

[3] As highlighted in an annual disaster report 2010, on January 12th 2011, the Prime Minister of Haiti updated the mortality figures and added 93,430 people to the death toll, making a total of 316,000 deaths. At present, this figure still needs validating by CRED and has therefore not been included.

[4] www.bt.cdc.gov/situationawareness/haiticholera/Flash/bt/atlas.html

[5] CRED, Guha-Sapir D., Vos F., Below R., Ponserre S., (2012), *Annual disaster statistical review 2011: the numbers and trends*, Ciaco Imprimerie, Louvain-la-Neuve

along a stretch of coast that has suffered so many tsunamis over the centuries and has been nicknamed “tsunami alley”[6]. A certain time is still required to trace a clear path for development based on political decisions such as the shutting down or otherwise of the nuclear energy plants.

The year 2012 brought a crisis to a locality nearby where this research was written. Following the Italian earthquake at L’Aquila in 2009–a crisis which the city will probably not recover from for another ten years–three earthquakes of magnitude 5.2, 5.8 and 5.1 were registered 300 kilometres to the north, in the surroundings of Modena, resulting in 27 deaths and damage costs of more than 13 billion Euros in an area where fewer than 40% of the houses were left safe after the quakes. Even if any comparison with Japan and Haiti is redundant, one whole year after the disaster only a part of the factories and houses have been repaired, while the cultural heritage will take many years to return to its original splendour. 15,000 were forced to leave their homes for several months and, if the majority of them have now returned, a certain number are still displaced[7].

ITALY

FIG. 0.8: MODENESI TOWER, ITALY

This thesis was reviewed just after the passage of Hurricane Sandy on the east coast of the United States, the second-costliest Atlantic hurricane in history, only surpassed by Hurricane Katrina in 2005.

UNITED STATES

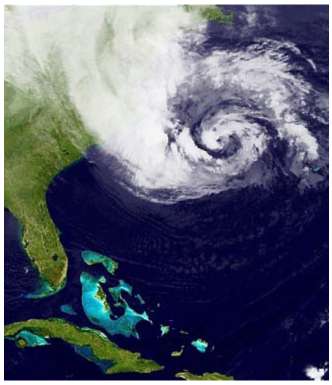


FIG. 0.9: HURRICANE SANDY

Hurricanes reveal, as Americans already knew to their cost, that even the most developed country finds it hard to mitigate the power of nature. The US was prepared for the hurricane: experts constantly monitored the progress and movements of the storm, citizens had been evacuated, barriers erected and risky locations like power plants or hospitals protected. Even so , over 185 deaths and hundreds of injuries occurred and over 8 million people were left without electricity for several days. New York experienced the largest flood ever seen in the last century. Everything resulted in more than 52 billion dollars in damage[8] which had still not been calculated precisely at the time this dissertation was submitted.

Haiti, Japan, Italy, and the US are only four different scenarios of four completely different crises in terms of dimension, impact, and background out of the thousands that have occurred over the last ten years. Seeing that the average number of disasters per year in the decade 2001-2011 was around 385, affecting more than 120 countries, one can imagine how complex and diversified the field of sheltering can be. Therefore, to come up with useful research on the topic, the starting point needs to be based on a careful definition of the problem and its limits. Part 1 serves this function: due to the fact that the sheltering process is complex and cannot be addressed linearly, a complex analysis by means of seven fundamental topics will be described.

The selected topics are, on the one hand, generic, with the ambition to cover the whole spectrum of issues that affect the sheltering process and, on the other, go deeper into discussing and presenting possible solutions. Topics are interdependent from one another

[6] *Japan one year on: What's changed?,* CNN

[7] Data and numbers: www.protezionecivile.gov.it

[8] Pielke R., *Hurricanes and Human Choice,* WSJ.

but readers can look over abstracts to follow the whole structure in the event of skipping certain passages.

Topics are presented based on a contrast of different approaches, all of which are/have been applied in emergencies. These contrasts cannot be resolved simply by choosing one of the options presented; on the contrary , each emergency case requires specific solutions which are, at the moment, based on "good practice" or "experience"[9] which balances those contrasts to find compromises.

INTRODUCTION OF UNCERTAINTIES

New solutions are, therefore, difficult to apply due to the fact that there is no reference for them or their results. The introduction of uncertainties in an already complex context which is fluid is considered a high risk which nobody would like to take responsibility for. Moreover, new solutions may generate consequences that are not really predictable in advance (for example the acceptance of solutions by local people, or secondary uses of them when the emergency is over).

Last but not least, the primary role of NGOs is to directly aid victims in terms of medical, economic and sheltering support and, as a consequence, they have no intention (but also no time, money or expertise) of investing in and pursuing innovation. Who then should be taking the lead?

Here it comes down to the figure of the researcher (no matter whether engineer, architect, designer or human scientist) who is in a key position to steer a process in which different skills are amassed and combined. Experience from the humanitarian fields (through NGOs and local authorities), the latest developments in new technology also from different sectors remote from the humanitarian one (through the work of universities and scientific centres), production and manufacturing processes (through input from industry), the background of each affected area (including its cultural habits, tradition and construction methods) are selected and mixed. This systematic approach is the only way to translate the enormous amount of data, knowledge and experience into something useful and applicable by partners who are dealing with emergencies day after day.

SYSTEMIC APPROACH

NEW DESIGN

FIG. 0.10: THE RECOVER DISASTER RELIEF SHELTER

Conversely, while searching on the Web, for example, or looking at the incredible numbers of design competitions organized with the aim of solving the problem of sheltering, one can find hundreds of solutions meant to be applied in emergencies that will never pass muster. What is the reason for this? Most of these solutions do have architectural or technological value but lack consistency in terms of usability or reliability. Besides , even the few ideas of value usually have no chance of being applied, the reason being that the approach that guided the design process of these solutions is lacking in some crucial aspects. In these cases, innovation is pursued, forcing the application of completely new designs or focusing on features or characteristics which are, most of the time, not needed. Moreover, the costs/benefits ratio or the production process itself are not usually taken well into account.

Even if, from a designer's point of view, it might be seen as a little frustrating, in the humanitarian sector it is clear that there is not much to design or invent (the myth of the

[9] Corsellis and Vitale, (2005) SAME: Shelter Assessment Monitoring and Evaluation, p. 136.

perfect tent disappeared decades ago) while, conversely, there are a lot of smaller issues to resolve or revise. This is probably also one of the reasons why the industrial sector is not really investing in innovation in such a field even if the business return, would be, unfortunately, quite considerable.

KEY ROLE OF THE END-USER

Industries blame players within the humanitarian sector for keeping them out of any decision process and NGOs usually do so to avoid external pressure coming from private interests. This is undoubtedly crucial with respect to the centrality of the end-user instead of the interests of third parties. However, this approach does not stimulate the development of solutions but, on the contrary , results in an oligopoly or, sometimes, even a monopoly of suppliers.

REQUIREMENTS

Innovation based on a systematic approach, should arise out of different drivers: experience, technology, materials, background, culture, and production are all on the same level. Unfortunately, at the present time, product development in the humanitarian field is simply based on the fulfilment of certain requirements set by NGOs and then published, for example, in the Emergency Items Catalogue[10].

FIGURE 0.11: EMERGENCY ITEMS CATALOGUE

These requirements are set by NGOs after endless discussions but they seem far from mature. On the one hand, we can clearly see that NGOs are not willing to take the responsibility for choices, while on the other, there is no real reason to blame them because it is probably not their role and they do not have the skills to define them.

The only possibility, at least at the beginning of the innovation process, is to accept that the set of design requirements in this process are more liquid and dynamic. Starting by having the right requirements is difficult even in a traditional design process. We can well imagine how it might be in the case of humanitarian relief.

IDENTIFICATION OF REQUIREMENTS

Real requirements are complex to identify for several reasons. First of all, it is difficult to have a clear overview of the state-of-the-art and even if "good practices" somehow evaluate past works, this is not done systematically and, in addition, is frequently limited to a specific organisation in a specific period of time. It is virtually impossible to overlap data coming from different NGOs at different times and for different disasters.

GO BEYOND REQUIREMENTS

The second reason is that humanitarian relief is based on volunteers' experiences and effort. However, they only work on certain specific tasks, sometimes lack particular skills and, due to their frontline position, cannot have a global view. Therefore, they are not the ones who can produce this list of requirements. Their coordinators are probably the only ones able to do so but they too are working in the field and have higher priorities than systematically evaluating the work that has been done. The role of the researcher is for these reasons, crucial. As an external, he/she should have the ability to go beyond requirements and offer processes and solutions without any fear, prepared for the fact that new systems are going to introduce new demands and unexpected requirements that will be solved on the go. To succeed in this goal it is crucial, on the one hand, to arouse the interest of specialists in the field and, on the other, to slowly change the attitude of the humanitarian sector and gradually incorporate these new competences.

[10] Emergency items catalogue IFRC, Volume 1, available from: procurement.ifrc.org/catalogue

COLLABORATIVE PROJECTS

R&D and the humanitarian sector need to find overlapping areas where innovation is in the hands of multidisciplinary consortia led by researchers and based on a new collaborative and systemic approach in which all players are asked to make their specific contributions[11], while bearing clearly in mind the ultimate goal of the innovation process: a better sheltering process able to improve victims' quality of life and lead to rapid development.

[11] www.speedkits.eu

1 INNOVATION AND EMERGENCY

Every day, the humanitarian sector deals with tremendous crises, both natural and human. The sheltering process is considered crucial in all phases, from relief to recovery and development which greatly influence the life quality of the affected population. The emergency phases require dedicated processes and products to support humanitarian activities. The increasing number of emergencies, the tremendous impact of some of the latest larger ones, together with climate change and the increase in high-density urban areas calls for urgent innovation in the field. But the humanitarian sector is opposed to change for several reasons. The reliability of processes and products is fundamental and is evaluated based on past experience; this is the reason why novelties are difficult to introduce. Moreover, the introduction of new variables, not applied before, is considered too high a risk and nobody would like to test anything out on victims already affected by disasters. NGOs are dealing with the contingency of the crisis and, even if they concentrate on the importance of the preparedness phase, they do not have the possibility, in terms of time, money, and knowhow to lead the innovation process. A few exceptions have arisen over the last few years[1] which provide extra proof of the great need for innovation. The innovation process is based on an incremental development of existing products or processes starting from evaluation of past work. Unfortunately, on the one hand, this evaluation is not done systematically or completely and, on the other, a marked leap into innovation is never made. This author thinks that to succeed, the humanitarian sector should prioritise innovation and risk-taking in policy and practice: e.g. new processes and products could be borrowed from other fields such as leisure and sport through a process of knowledge transfer and, sometimes, "downgrading" of lightweight architecture which could inspire the whole sector. In the beginning, these new solutions could be applied as support for volunteers and NGOs. Only in a second stage, after an extensive campaign of tests, could they be applied to local populations. A systemic design process is able to drive

[1] SRU: Shelter Research Unit

innovation and should include all players: NGOs, research centres, industry. In this way, the risks of failure are minimized. Researchers should take the leadership of this innovation process.

1.1 Processes and products

Humanitarian relief is an intense activity which requires effectiveness and rapidity in terms of planning, logistics, coordination and prioritization of actions. Processes and products, especially in the very first phase of the emergency, have a clear task: to rescue[2] lives, at any cost. If the second and third phases after an emergency focus more on the recovery[3] towards development[45] of the affected community and area, the first hours are dedicated to finding missing people and saving lives.

Sheltering becomes an issue right from the very first hours, for example, to provide operating theatres or to protect the injured and more vulnerable categories such as the elderly, the disabled, or children. On the other hand, although sheltering, considered as an activity to provide a dry, safe, decorous dwelling for victims, should start as soon as possible, it usually cannot begin until 48-72 hours after the emergency strikes due to logistical problems and other priorities.

PROCESS AND PRODUCTS

The sheltering activity has to be considered more in terms of processes rather than products; nevertheless , products are the tools which make processes possible. Different tools and different processes are applied according to the particular emergency and its phases. Every emergency is different, but the very first hours are frequently the same in any disaster. When time passes, each crisis reveals its own peculiarity and it is here when processes become crucial. For example, an earthquake in Europe cannot be approached in the same way as one in Indonesia due to the cultural background and the local economy. The same is true for a crisis that happens today: it cannot be solved by methods that were satisfactory twenty years ago. Sheltering is, therefore a dynamic, ongoing process influenced by a large number of factors.

IMPACTS AND PERCEPTIONS OF EMERGENCIES

In recent years, the number of emergencies and their impact in terms of victims and economic damage has dramatically increased[6]. The rise in these numbers is due to several reasons: first of all, we have to consider that we are currently able to report all crises all over the world, something that was difficult to do in the past. However, what is certain is that climate changes together with the increase in high-density urbanized areas are factors which worsen the consequences of any crisis. The sheer density of today's cities makes the

---

[2] See appendix 1

[3] See appendix 1

[4] See appendix 1

[5] World Bank, (2010), *Safer Homes, Stronger Communities, A Handbook for Reconstructing after Natural Disasters,* The World Bank, Washington DC

[6] Em-dat database: www.emdat.be

rescue phase slower and more difficult[7]. In addition, debt disposal problems and the displacement of people have to be taken into account. At the same time, humanitarian standards during the emergency phases have risen consistently[8] under the pressure of public opinion and the unrelenting media spotlight.

Starting from this background, it is clear that innovation is required in terms of both products and processes: as an example, innovation can be introduced in both materials and construction technology, but also in the development of new methods based, for example, on the "ready-to-use" rather than the "Kit" approach[9]. Sadly, in humanitarian sectors, innovation may be a common enough word but the facts tell that only a minimum part of the effort in this direction is actually applied in the field. The reason is manifold: bottlenecks are present and consistent and concern a variety of aspects such as the reliability of the solutions, the risks of failure linked to novelties, the responsibility for the choice taken, together with the problem of taking leadership of the innovation process.

FIGURE 1.1: 2011, JAPAN AFTER TSUNAMI

All of these aspects will be presented in the following pages. The current innovation process will be analysed and a discussion of the most relevant fields in which innovation would be required will be presented. The ultimate goal of this analysis is to present possible ways to innovate within the various sectors.

1.2. Reliability

Emergencies require reliable solutions to overcome the crisis and support victims. Any solution which is not reliable could turn into something ineffective or even dangerous because it would only make matters worse. An unreliable solution is not only a waste of money in itself but brings about various forms of damage starting from logistics (instead of the ineffective solution, something else could have been sent and, in addition, a second delivery to substitute the items has to be taken into account) to the development process (all other solutions based on the unreliable support should be revised or even cancelled. In the case of modular or incremental systems the effectiveness of the whole process should be checked).

FIGURE 1.2: HAITI, COLLAPSE OF A SHELTER MOUNTED IN DANGEROUS AREA

SOME DEFINITIONS

Several definitions of reliability can be found in different sources; according to the Oxford Dictionary of the US Military[10]:

- *reliability* is the ability of an item to perform a required function under stated conditions for a specified period of time.

Looking more into specifically semantic areas, the McGraw-Hill Science & Technology Dictionary[11] defines reliability as follows:

---

[7] Shelter Centre (2010 c) *Urban shelter guidelines: Assistance in urban areas to populations affected by humanitarian crises*, Shelter Centre, Geneva.

[8] Sphere project, The (2004), *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response*, Geneva,

[9] See chapter 7

[10] The Oxford Essential Dictionary of the U.S. Military, Oxford University Press Staff, Berkley Books, 2001

- *(engineering)* the probability that a component part, equipment or system will satisfactorily perform its intended function under given circumstances, such as environmental conditions, limitations as to operating time, and frequency and thoroughness of maintenance for a specified period of time.

Looking at the second definition, it is clear that to identify the reliability of one component, several factors need to be clear, such as the *function* of the component itself, the *environmental conditions*, the *operational time* and its expected *lifespan*. Unfortunately, in humanitarian relief, this is not as simple as it seems: typically, not all of these factors are actually known in advance.

FUNCTION

It seems unbelievable, but even the *function* is, sometimes, not well definable during the design phase. In fact, components which are designed and distributed for a specific purpose are then applied and reused in countless options which hinge on shortage of material, the needs raised in a specific moment, and the different culture in which they are being applied. Therefore, something that was designed to shelter families is then used to protect food, while packaging elements are often applied as construction systems.

FIG. 1.3: ERITREA, "RONDA" STRUCTURE MODIFIED WITH STEEL ELEMENTS

FIG. 1.4: ERITREA, STEEL ELEMENTS SOLD AND REUSED

The usability of items is closely related to the cultural and regional habits of the affected population. Especially in third world countries it is, therefore, extremely difficult to predict, as outsiders, how an element will be accepted and considered by the local community.

To add more variables, in an emergency anything which is provided to the affected population is intended to be as flexible as possible; if the first use can be foreseen and somehow "guided" through training sessions, a flexible and effective component should be open and adaptable to different applications: second, third or fourth uses cannot be predicted.

However, usually problems do not arise at a later stage: in the event of elements lasting, conceivably their key features appeared clearly and this is the reason why people used them in that way. Conversely, the first use, when people improvise their shelter solution, is the most critical, because users may not have experience on what to expect in terms of performance or durability.

ENVIRONMENTAL CONDITIONS

Environmental conditions are also extremely difficult to foresee. Even if a huge effort on mapping[12] the most dangerous locations around the world in terms of climatic conditions and hazards has been made in the past as shown by the literature[13], and events are reported every year by international agencies[14], every location experiences particular and local climatic conditions and has specific risks related for example to soil condition, water availability, and so on.

[11] McGraw-Hill Science & Technology Dictionary

[12] Alexander D.E., (1993), *Natural Disasters, Disaster and hazard mapping*, Springer

[13] Peduzzi P., Dao H., Herold C., (2005), *Mapping Disastrous Natural Hazards Using Global Datasets., In Natural hazard*, Springer

[14] www.emdat.be

Moreover, truly efficient mapping would not include only climatic conditions but should be able to offer an overview of available technologies, materials, and production[15].

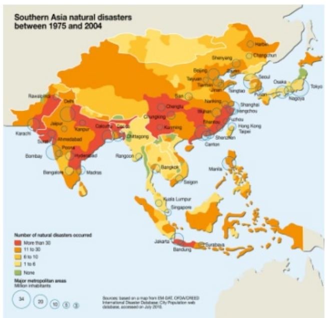


FIG. 1.5: SOUTHERN ASIA NATURAL DISASTER BETWEEN 1975 AND 2004

To be trustworthy, this range of information needs to be gathered in collaboration with local communities especially in areas where " outsiders" are not welcome (e.g. wars or civil conflicts). The weaknesses of this kind of database lie in the cost of gathering the right kind of information and keeping it up-to date. Every few years, economic scenarios, for example, can radically change, turning a useful tool into something no longer reliable.

OPERATIONAL TIME

The *operational time* of the elements provided in an emergency is another of the big unknowns. Some elements are only designed to last for a very short period. Conversely, elements designed to last several years end up being reused in different ways because needs are complex and change over time. The chance that any single component can be reused and continue its life when the emergency is over is precious.

However, durability is generally related to costs: it is impossible to expect a lifespan of several years in harsh conditions such as continuous exposure to UV light and, in the case of tropical climates, to humid conditions. Every element must be designed weighing up the performance/cost ratio in the best possible way, considering that a process that substitutes components is not in itself negative. In fact, if it is done properly, a natural process of substituting components might stimulate the local economy and, at the same time, offer the best solution for a specific occasion.

FIG. 1.6: EXAMPLE OF INTEGRATION OF DIFFERENT MATERIALS

To come up with the best trade-off between cheap short term solutions and more expensive lasting ones, the starting point might be to forecast how long the emergency phase will last. Unfortunately, most of the time, this is wholly unpredictable. As a result, a design strategy is established. Optimization of elements should follow specific requirements which in the case of reliability, deal, for example, with safety factors.

Which of these needs to be taken into account? Are they based on a potential return risk of a few months or years? Or is it better to stick to traditional building construction customs with a potential return of 50 years? It is obvious that choosing the first option would generate consistent savings in terms of the amount of material and a subsequent reduction in costs in terms of transportation, but also positively influence the speed of production, delivery and construction. Most of the time, at this point, the design strategy is stuck. The aim of the next pages is also to overcome this impasse.

LIFE SPAN

Lifespan is not only related to a possible second and third use but also to the end-life of the elements provided in an emergency and is unquestionably something difficult to control. At any rate , just to have a rough idea, any component delivered in the field costs twice the original amount, due to transportation and, occasionally, taxes. Therefore the generation of waste materials (which means a consequent disposal cost to be taken into account) needs to be definitively limited.

A local population knows this only too well and tries to reuse what has been provided in different ways, and sometimes, also in wrong ones. The reliability of components used in ways which were not foreseen is, most of the time, critical, and difficult to control. To

[15] Advanced mapping references

achieve this goal, the investigation of different possible uses must be taken into consideration from the very beginning of the sheltering process.

Even if these uses are almost impossible to foresee and change according to the cultural background of the affected area, experience from the field is a precious way to have an overview of a range of possible uses that have popped into the minds of stricken populations.

1.3. Risks

EFFECT OF UNCERTAINTY ON OBJECTIVES

Humanitarian relief deals with risks every day. Emergency and risk are strictly linked to each other in both directions. Emergencies generate risks as soon as they affect human equilibrium (in physical and economic terms). In the ISO 73:2009, risk is defined as the "effect of uncertainty on objectives" where effect is "a deviation from the expected" (if the expected is normality, an unexpected occasion can sometimes turn into an emergency), while uncertainty is "the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequence, or likelihood" and risk is "often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence"[16].

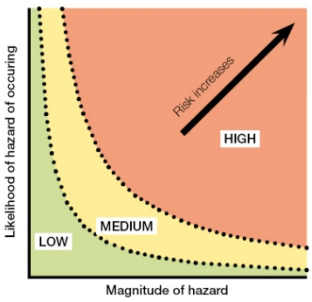


FIG. 1.7: GRAPHIC REPRESENTATION OF RISK AS FACTOR OF LIKELIHOOD AND MAGNITUDE

Considering the definition of risk in disaster occasions, it is useful to quote Cardona[17] who defines it as: "the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon and consequently the product of specific risk and elements at risk". Moreover, according to Crichton, "Risk is the probability of a loss and this depends on three elements: *hazard*, *vulnerability*, and *exposure*. If any of these three elements in risk increases or decreases, then the risk increases or decreases respectively"[18].

The ability to cope and react to risks is called *resilience* and its characteristics are presented further on in this chapter. The goal of humanitarian relief is to minimize risks on the one hand, by levering on hazard, vulnerability and exposure through processes of prevention and mitigation and, on the other, to increase resilience through long-lasting actions, for example, based on education and economic development. Innovation in the field passes through a deep understanding of these concepts.

[16] ISO 73:2009

[17] Cardona O.D. (2003), *The need to rethink the concept of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management.*

[18] Crichton, D. (1999), The Risk Triangle, in Ingleton, J. (ed.), Natural Disaster Management, Tudor Rose, London.

1.3.1 Hazard

In July 2008, the CRED (Centre for Research on the Epidemiology of Disasters) and MünichRe released a common "Disaster Category Classification for Operational Databases". This new common classification represents a first step in the development of a standardized international classification of disasters[19].

Hazard is defined as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro meteorological and biological) or induced by human processes (environmental degradation and technological hazards). Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterized by its location, intensity, frequency and probability"[20].

MAPPING OF HAZARD

According to these characteristics, each hazard becomes unique and therefore requires specific *preparation*, *mitigation* and *response* actions. However, to reduce the risk of the impact of hazards, they have been studied and mapped all over the world in recent years. Even though hazard cannot be avoided, its consequences can be limited in two ways. First of all, risk can be reduced trough a series of strategies based on the reduction of the *vulnerability* of specific areas and populations. Secondly, risk can be avoided by understanding well which *catastrophe*[21] could occur in a specific area (*exposure*): hazard assessment is the starting point and is based on a definition of several data such as frequency, magnitude or intensity, duration, area of extent, speed of onset. Several institutes such as the UNU-EHS produce annual reports on hazard assessment and its relation to vulnerability and exposure.

1.3.2 Vulnerability

Each population has its own degree of vulnerability. In addition, vulnerability changes according to individuals and groups within a population. On exposure to different hazards, various groups will suffer differently depending on their susceptibility and level of exposure. The relative risk between different ages, sexes, and ethnic groups will depend on who is vulnerable, in what way, and the types of risk these groups are exposed to.

Vulnerability may be physical (certain groups are particularly vulnerable to micronutrient deficiencies or infection); it may be related to degrees of trauma suffered during the emergency event (rape, torture, loss of family, shock); it may be related to social and political factors and the amount of influence an individual has (i.e., ethnic origin,

[19] It distinguishes two generic categories for disasters (natural and technological), the natural disaster category being divided into six sub-groups: Biological, Geophysical, Climatological, Hydrological, Meteorological and Extra-Terrestrial disasters. Each sub-group in turn covers 12 disaster types and more than 32 sub-types.

[20] UNISDR (2008) *Disaster Risk Reduction Strategies and Risk Management Practices: Critical Elements for Adaptation to Climate Change,* Inter agency.

[21] See appendix 1

religion, poverty); or it may be related to how groups are served differently by national and international assistance programmes (i.e., adults may receive food from general food distribution only, whereas children may have multiple food income sources)[22].

FACTORS WHICH INFLUENCE VULNERABILITY

Vulnerability to natural disasters comes from many factors: population growth and density, unplanned human settlements, poor construction, lack of adequate infrastructure, social inequality, poverty and poor environmental management[23]. Resource rights issues permeate many of these.

The poor are particularly vulnerable; due to the type of housing they rely on, the marginal lands they inhabit, the liquidity constraints they face, their inability to escape disaster zones, as well as their limited education and awareness of danger[24].

In addition, looking at a country level, less developed countries are more vulnerable to natural hazards than industrialized countries are because of a lack of understanding, education, infrastructure, building codes, etc. Poverty also plays a role since this leads to poor building structures, increased population density and lack of communication and infrastructure. Governments also have their responsibilities: countries where governments are weaker end up more vulnerable to natural hazards.

HUMAN FACTORS

Human intervention in natural processes is one of the major factors that affect vulnerability through the development and habitation of lands susceptible to hazards. This is the case of building on areas subject to floods, slopes subject to landslides, coastlines subject to hurricanes and floods, or volcanic slopes subject to volcanic eruptions.

The actions of Man can also increase the severity or frequency of a natural disaster: this happens when there is overgrazing or deforestation leading to more severe erosion (floods, landslides), removing groundwater leading to subsidence, the construction of roads on unstable slopes leading to landslides, or even contributing to global warming resulting in more severe storms. Vulnerability is therefore strictly linked to the actions of a specific community, whether planned or otherwise.

SUSCEPTIBILITY COPING ADAPTATION

However, resilience is a combination of factors and, as clearly shown by the World Risk Report 2011[25] it can be considered a mixture of three main ones: susceptibility, coping and adaptation. Susceptibility is the likelihood of suffering harm, coping is the capacity to reduce negative consequences, and adaptation is the capacity for long-term strategies for societal change. Susceptibility, coping and adaptation are three levers which can positively influence reaction to a disaster, reducing its impact and speeding up development. Unfortunately, humanitarian relief does not usually enjoy a free hand in those areas which are typically demanded by local authorities. This is the same in the case of controlling exposure.

---

[22]Passage freely interpreted from: *Targeting the vulnerable in emergency situations: who is vulnerable?* Austen P. D., In The Lancet vol. 348, 1996

[23] Inter-American Development Bank, Reducing Vulnerability to Natural Disasters, May 1999.

[24] Dayton-Johnson, J., *"Natural Disasters and Adaptive Capacity,"* OECD Working Paper 237, 2004, p.18

[25] UNU-EHS (2011) *World Risk Report 2011.*

1.3.3 Exposure

It is clear that, the higher the exposure of a community, the higher the risk that may occur in terms of lives lost and economic/social losses. In addition, exposure can be differentiated into temporal and spatial components. The temporal component of exposure concerns the return period of hazards in a specific location. This return period can be seasonal, for example in the case of hurricanes or tropical storms, but can also centuries long as is the case for earthquakes (the Italian Emilia Romagna earthquakes of 2011 followed ones of a similar magnitude which occurred in the same areas in the 16th century) and volcanic eruptions (for Vesuvius, Naples, scientists estimate a return period of 2,000 years.).

RETURN PERIOD

Nonetheless, the majority of hazards have return periods on a human timescale. This reflects a statistical measurement of how often a hazard event of a given magnitude and intensity will occur. The frequency is measured in terms of a hazard's recurrence interval. Extreme events which occur every hundred years or so have very low frequencies but very high magnitudes in terms of destructive capacity. This means that an event considered as a hundred-year hazard can cause more severe damage than a five-year one.

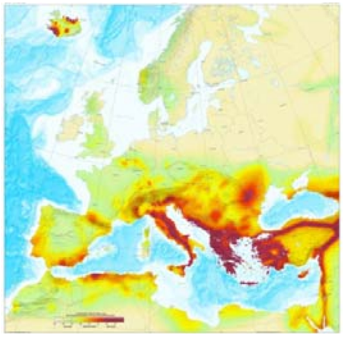


FIG. 1.8: EUROPEAN-MEDITERRANEAN SEISMIC HAZARD MAP

If a society or a country has no exposure to natural hazards, then the development of strategies for dealing with them may be neglected. Within the World Risk Index[26], exposure is related to the potential average number of individuals who are exposed each year to specific hazards such as earthquakes, storms, droughts and floods.

Despite the USA and Japan having the highest economic exposure to natural hazards, it is the emerging economies of China, India, the Philippines and Indonesia which pose the most risk to investors due to a lack of capacity to combat the impact of a major disaster. According to the Natural Hazards Risk Atlas 2011[27], these countries are not only at "high" and "extreme risk" from economic exposure to natural hazards such as earthquakes, tsunamis, tropical cyclones, floods and drought, but they also lack the resilience to mitigate the disruption a major event would bring to their societies and economies.

1.3.4 Resilience

Risk is linked to resilience which is defined as: "the capacity of a system, community or society to resist or to change in order that it may obtain an acceptable level in functioning and structure. This is determined by the degree to which the social system is capable of organising itself, and the ability to increase its capacity for learning and adaptation, including the capacity to recover from a disaster."[28]

Resilience is therefore seen as the ability of systems to respond and adapt effectively to changing circumstances. In concrete terms, it is the ability of critical physical

[26] UNU-EHS (2011) *World Risk Report 2011*

[27] NRHA: *Natural Hazards Risk Atlas 2011*, Maplecroft.

[28] IFRC (2012), *Road to resilience: Bridging relief and development for a more sustainable future.*

infrastructures to absorb shocks[29]. From a more psychological point of view, it is the process of adaptation and a set of skills, capacities, behaviour and actions required to deal with adversity.

Resilience "focuses on attributes such as persistence, adaptability, variability and unpredictability–all of which are at the heart of evolution and development"[30].

CHARACTERISTICS OF RESILIENCE

Resilience as applied to ecosystems or socio-ecological systems has three defining characteristics:

1) the amount of change the system can undergo and still retain the same control over function and structure;
2) the degree to which the system is capable of self-organisation (recovery); and
3) the ability to build and increase capacity for learning and adaptation[31].

The last point emphasizes the primary difference between resilience in ecosystems and social systems – the capacity for forward planning. This adaptive capacity, which, simply put, refers to the ability of the players in a system to influence or manage their resilience, is dependent on institutions and systems that learn and store knowledge[32].

RESOURCE RIGHTS

The resilience of groups and individuals can be strengthened by their resource rights. Control and access to such resources influences spatial planning in areas vulnerable to natural disasters, encourages investment in resilience, and helps reduce environmental degradation which only heightens vulnerability[33].

WORLD RISK INDEX

Concentrating on governance, the World Risk Index argues that not every extreme, large-scale hazard has to end in catastrophe and that disaster risk is actually determined by a combination of exposure to hazards and social vulnerability. This is the case of the Emilian earthquakes that occurred in June 2012 in one of Italy's most economically productive regions, causing damage to the agricultural, food and biomedical industries resulting in a total estimated economic damage of 13.2 billion Euros[34]. Although the damage caused by the earthquakes was extensive, the situation did not turn into a humanitarian disaster as Italy is well placed to deal with such events. In the UN's World Risk Index, Italy is categorized as "low risk", indicating that the country can handle natural hazards and prevent them from becoming natural disasters.

This provides a compelling conceptual framework for developing scientific expertise and social resources imperative to preparing for and mitigating future disasters. While no

---

[29] Institute for National Security and Counterterrorism, Project on Resilience and Security, "Resilience in Post-Conflict Reconstruction and Natural Disasters" Workshop Report, Syracuse University, 9 March 2009

[30] Holling C.S., Walker B. (2003) *Resilience Defined*, Internet Encyclopaedia of Ecological Economics.

[31] Resilience Alliance (2001) www.resalliance.org .

[32] Walker, B. and J. A. Meyers. (2004) "Thresholds in ecological and social–ecological systems: a developing database" Ecology and Society 9(2), p.3.

[33] Brown O., Crawford A., Hammill A., (2006), *Natural Disasters and Resource Rights: Building resilience, rebuilding lives,* IISD.

[34] Data from: www.protezionecivile.gov.it

index or report can encompass the complexity and magnitude of the world's exposure and vulnerability to hazards, this World Risk Index from the UN is a clear example that researchers are moving beyond singular framings of hazards and risks and that the international community should be able to deal with them today and in the future[35].

1.3.5. Risk assessment and disaster risk reduction framework

To reduce the impact of natural hazards and related environmental and technological disaster, risk assessment is the basic strategy. This is based on administrative decisions and the organisation, operational skills and capacities of societies and communities. It comprises all kinds of activities, including structural and non-structural measures to avoid (prevention) or to limit (mitigation and preparedness) the adverse effects of hazards[36].
A disaster risk reduction framework consists of the following elements as described by the International Strategy for Disaster Reduction[37] and the Hyogo Framework for Action[38].

- Policies, institutions and national plans: to ensure that disaster risk reduction is a natural and local priority with a strong institutional basis for implementation;
- Risk identification: to assess, map and monitor disaster risks (hazard and vulnerability/capacity analysis) and enhance early warning systems, including forecasting, dissemination of warnings, preparedness measures and reaction capacities;
- Risk awareness and knowledge development through education, training, research and information sharing to build a culture of resilience at all levels;
- Reduce the underlying risk factors and apply disaster reduction measures in different related domains, such as environmental management, land-use and urban planning, protection of critical facilities, application of science and technology, carious forms of partnership and networking and the use of financial instruments;
- Strengthen disaster preparedness to reduce the impact of disaster and ensure effective response at all levels.

FROM EMERGENCY-FIRST TO VULNERABILITY-FIRST

All the factors that contribute to the risk reduction framework are equally relevant. Innovation is possible at every level but requires time and leadership to take the most vulnerable communities and areas by the hand and guide them through a process of resilience. A new perspective is required: humanitarian agencies should try to go beyond "emergency-first" innovation models to establish "vulnerability-first" approaches to

---

[35] UNU-EHS (2011) World risk report 2011, available at: http://ihrrblog.org/2011/09/26/2011-un-world-risk-index/

[36] UNISDR (2008) *Disaster Risk Reduction Strategies and Risk Management Practices: Critical Elements for Adaptation to Climate Change.*

[37] UNISDR (2012) *Making cities resilience report 2012* Available at: www.unisdr.org/campaign

[38] UNISDR (2005) *Hyogo Framework for Action 2005-2015: Building the resilience of nations and communities to disasters*, Extract from the final report of the World Conference on Disaster Reduction

renovate the sector. This suggested shift is based on the fact that it is much more effective to prevent disasters than to respond to them, something equally true for the wellbeing of humans and communities and populations at large, especially in cases where vulnerability is high and the consequences can be greater.

1.4. The innovation process

Innovation is probably one of the most frequently discussed topics of recent years in every field. Innovation is linked to development, progress and competition, and has been investigated in depth over the last two decades.

The innovation process in industries, from early sketches to large-scale application is often compared to evolution. Organisations, like organisms, survive and grow by means of adaptation, selecting new elements which help them prosper in a particular environment. Organisations that innovate are more likely to thrive. Despite the complexity and unpredictability of innovation, a successful innovation process usually includes some or all of five key elements which have been clearly defined by Maidique[39]:

1) recognition of a problem, challenge or opportunity;
2) invention of an idea or solution to the problem, or a way to exploit an opportunity;
3) development of the innovation by creating practical plans and guidelines;
4) implementation of the innovation in terms of changed operating practice; and
5) diffusion of the innovation to ensure its wider adoption for benefits outside the original setting.

This does not mean that all innovations are sequential, linear processes with clearly defined stages. Rather, these are broad and overlapping phases through which many innovations pass. Although idealized, this model is useful because it allows different processes to be understood and compared – helping organisations to “repeat the trick” – by providing guidance on how innovations progress[40].

CLOSES R&D MODEL OF INNOVATION

Modern innovation theory derives from early twentieth-century capitalism, based on individual firms aiming to develop new products through investment in research and development (R&D), or exploiting new markets. This “closed” innovation model has been central to the maturation of industrial capitalism.

OPEN STRATEGIES OF INNOVATION

However, as information technology grows in importance, and users become less passive, this closed model is being replaced by more “open” strategies based on recognition of the fact that the sources of ideas and the drivers of the process have become increasingly

[39] Maidique, A.M. (1984), *Entrepreneurs, Champions and Technological Innovation,* Sloan Management Review, Harvard

[40] ALNAP, Ramalingam B., Scriven K. and Foley C. (2009 d) *8th review on humanitarian sector, Innovations in International humanitarian action*

diffuse. In particular, open, democratized innovation models suggest that many of the most radical innovations come not from experts and specialists in R&D but from frontline staff, consumers, users and suppliers – those traditionally excluded from innovations processes.

4 Ps MODEL

The general model of the "4 Ps" developed by John Bessant and Joe Tidd[41] is here considered the starting point to link innovation and the humanitarian sector. According to the "4 Ps" model, innovations is related to four different aspects:

1) *products*, e.g. improved shelters or water sanitation and purification to raise the health level and avoid malnutrition;
2) *processes*, e.g. methods for stockpiling and tracking goods, shelter processes, improved coordination, packaging and delivery or improving learning and education;
3) the *position* of an organisation and its work in relation to key stakeholders, for example by changing an organisation's public profile or by changing attitudes to an area of work such as sheltering or WASH;
4) *paradigms* or combined attitudes and beliefs determining the fundamental approach to humanitarian work, such as calls for paradigmatic shifts in the humanitarian business models towards beneficiary participation, local ownership and development of capacity.

In terms of scope, innovations can also be framed as incremental and continuous improvements to existing products, processes, positions or paradigms which may enable either reductions in cost or improved features. At the other end of the scale, some innovations can be far-reaching and involve new and radical shifts in thinking about a particular product or service, or even an entire industry. Such radical – or discontinuous – innovations can lead to the obsolescence of existing organisations.

Exploring these ideas in the context of humanitarian work gives a new way of understanding and harnessing organisations' creative potential. This thesis will mainly focus on the first and second factors which are generally more closely linked to the field of architecture, however the third and fourth will also be taken into account due to the intrinsic characteristics of the humanitarian field which is affected by position and paradigm innovations.

1.4.1. Learning from the private sector

INNOVATION IN PRIVATE SECTOR

Innovation in the private sector is mainly considered as a survival strategy. Either a company innovates its offer in terms of products, services, markets or applications or it does not survive the competition with other firms able to do the same job better. As listed in

[41] Tidd J., Bessant J., Pavitt K., (1997), *Managing innovation : integrating technological, market and organisational change*, John Wiley, Chicester.

the 8th ALNAP Review on the humanitarian sector[42], drivers of innovation in private sectors are well known, and are listed below divided into two macro areas: internal and external drivers.

Internal drivers include:

- shareholder demands for higher performance, profitability and returns;
- pressure to decrease costs;
- pressure to increase efficiency and effectiveness;
- shorter product life-cycles.

External drivers include:

- increased sector competition, especially through globalization and other sector dynamics;
- rising customer and stakeholder expectations;
- greater availability of potentially useful new technologies;
- changing economic, demographic and social contexts;
- the impact of stricter regulations;
- social concerns, e.g. for greater sustainability and accountability.

INNOVATION IN PUBLIC SECTOR

Meanwhile, innovation in the public sector is not based on the "survival imperative" as it is for the industrial one. The public sector does not usually follow the competitive rules of the market and therefore innovation is at best an "optional" extra. This is the reason why innovating in the humanitarian field is totally different from that which occurs in private sectors.

PRODUCT INNOVATION

However, as in the private sector, there may be a tendency to focus primarily on product-based innovations in the sector, which can in some cases prove detrimental. In the sheltering sector, for example, relief organisations are bombarded with different designs and prototypes for shelter-based innovations. Many of these are based on the idea that one single product can work in all settings.

Aid agencies themselves have had a tendency to focus on the delivery of tents and other shelter products, with incremental innovations being cited as a key approach. As we shall see in more depth later (Section 3.4), this product-based view can lead to inappropriate innovations; a different approach to innovation may be part of the answer to address the failures of shelter provision.

PROCESS INNOVATION

As with product innovations, the implementation focus of much relief work also means that process innovations are prevalent in the humanitarian sector. Because so many of the products used in relief settings were initially developed for non-relief contexts, a natural focus for innovation is to consider how a product might be used in resource-poor or rapidly changing settings such as those commonly faced by relief agencies. "The humanitarian community is built on innovation - on just getting things done despite a lack

[42] ALNAP, Ramalingam B., Scriven K. and Foley C. (2009 d) *8th review on humanitarian sector, Innovations in International humanitarian action*

of resources." From this perspective, humanitarian agencies could be said to innovate on a daily basis. No two humanitarian crises and no two recipients of aid are exactly the same, and so the process of getting assistance to where it is needed, as quickly and effectively as possible, is a constant process of creative adaptation and problem-solving.

1.4.2. The innovation process in the humanitarian sector

> *"It remains a mystery why, in an apparently entrepreneurial and still unregulated system, so few innovative and dynamic new agencies have appeared to fill the many gaps and opportunities in the humanitarian response…".*
> *"… As the system moves towards [consolidation], it must still urgently encourage innovation and entrepreneurialism whereby humanitarian agencies can make new discoveries and risk new approaches... [humanitarian agencies] need to prioritise innovation and risk-taking in the humanitarian politics and practice. If, in the next five years, the humanitarian system has only consolidated, it will have failed to take advantage of new ideas and will not have adapted to new opportunities"*[43], *(Slim, 2006, p. 24,30)*

INCREMENTAL IMPROVEMENTS IN PRACTICES

As clearly stated in the ALNAP Innovation in International Humanitarian Action (2009), "much ongoing work in the realm of humanitarian learning and accountability does not seek to generate new and different ways of operating. Rather, it focuses on existing practices, policies and norms of behaviour, and involves detecting and correcting deviations and variances from these standards, or finding ways in which standard operating procedure can be better implemented. The focus is on incremental improvements in practices."[44]

EVALUATIONS DO NO TELL ANYTHING NEW

We may hear that a lot of analysis and evaluation of what has been carried out has been and is being done but these data "tell us nothing new", nor do they help deliver novel and interesting perspectives on well known problems. Therefore it is clear that the current attempt to innovate does not contribute to an overall improvement in humanitarian actions. In this way, knowledge and experience are not stored and are only rarely transferred to other agencies and this information can easily be lost when "experts" change.

FIG. 1.9: HAITI: SHELTER LOCALLY IMPLEMENTED

A culture of innovation has not yet been introduced and accepted by humanitarian agencies and they have made no sustained attempt to stimulate a process of renovation. When good practice and new ideas arise, these tend to be disconnected and not well systematized to be applied on a second occasion.

---

[43] ALNAP, Slim, H (2006) *Global welfare: A realistic expectation for the international humanitarian system?* in ALNAP Review of Humanitarian Action: Evaluation Utilisation, Overseas Development Institute, London.

[44] ALNAP, Ramalingam B., Scriven K. and Foley C. (2009 d) *8th review on humanitarian sector, Innovations in International humanitarian action*

Consciously prioritising and managing innovations can provide an important and, as yet, under-utilized mechanism to improve humanitarian performance. Only over the last few years have efforts in this direction been made thanks to the work of ALNAP, research carried out at the Shelter centre, and the newborn SRU, Shelter Research Unit, which should fill the gap between theory and practice, statistical analysis and application in the field through an approach based on validation of the solution also from a technological point of view. At the moment, innovation still occurs on site during emergency phases which is definitely in contrast with the approach of "doing it in advance". As a consequence, the lack of preparation, testing and validation of an innovation is one of the reason why traditional solutions, even when they are not the best, are the ones most likely to be applied.

INNOVATION STILL ARISE ON SITE

IMPORTANCE OF SHARING INFORMATION

The precise reasons why innovation is rarely pursued in advance are complex and can be grouped into two macro areas: lack of knowledge and drivers. First of all, every situation is different and specific problems arises and are, therefore, difficult to predict. The importance of mapping, together with the experiences of past emergencies, becomes useless if the information is not shared among the various players (see Chapter 3: targeting and addressing the problem).

The fact that the sheltering process is threatened by uncertainties does not stimulate research which may well result in something that does work but is useless in the field. Secondly, innovation in the humanitarian sector is not impelled by the same drivers which are typical of the industrial sector. Market and profit rules are substituted by other factors. Social innovations have a key distinction compared to industrial ones: "they are primarily motivated by the goal of meeting a social need, and that the innovation is predominantly diffused through third-sector organisations whose purposes are social'[45]. In this respect, the traditional leverages which convince industries to push R&D are not present, especially in relation to the fact that this market seems difficult to enter.

MEETING SOCIAL NEEDS

SOCIAL INNOVATIONS

Understanding how social innovation works broadens the motivations for innovation beyond profit and public service: social innovations are usually driven by goals such as equity, rights, and the alleviation of suffering. The process of social innovation is traditionally based on new combinations or hybrids of existing elements, rather than ones which are wholly new in themselves. This derives from the fact that within the humanitarian sector there are no players who have economic, organisational and technical capabilities to develop something new, whereas there are a lot of players who deal daily with problems and try to find their own new solutions starting from the existing situation which may end up as effective innovations. The implementation of such combinations requires cutting across organisational, sector or disciplinary boundaries and is based on new social relationships between previously separate individuals and groups, contributing to the diffusion and embedding of the innovation, and increasing potential for further innovation.

---

[45] Mulgan G., Tucker S., Ali R. & Sanders B., (2007) Social Innovation. Oxford: Skoll centre for social entrepreneurship.
Available at: http://www. youngfoundation.org/files/images/03_07_What_it_is__SAID_.pdf

DIFFERENT LEVERAGES

Without the leverage of profit, it is essential to provide other incentives for innovation which will not be led by industries that cannot see an immediate return on their investment, or NGOs which lack time, knowhow and a large-scale view due to their role in the contingency of the emergency response. Only dedicated research groups or institutes would be able to steer this process by setting up consortia in which partnerships, based on a clear understanding of the skills of the different parties, are essential for innovation processes to work effectively. "This echoes private sector approaches, in which different kinds of players – government, private sector, universities and knowledge institutions – work together to increase the value generated from research investments"[46].

Innovation processes should be supported by effective information sharing, within and between organisations, and humanitarian agencies should aim to work in partnerships for innovation. Partners can usefully be selected from humanitarian counterparts and from beyond the sector.

INCENTIVES

Examples of incentives towards innovation can be of different kinds. First of all, support from the highest level of NGOs which encourage an innovative culture is required. Secondly, the interest of all stakeholders should be listened to and taken into consideration, including users and staff members who are the main source of inspiration for innovation. Thirdly, adequate resources in terms of funds but also equipment and facilities must be identified. Fourthly, a searching review evaluating past experience and the transformation of this knowhow into something that can be used as background for the greatest amount of players should be set up. Lastly, field tests should be considered a fundamental part of the development process in which specific experiments can be carried out in "safe" areas.

RISKS OF SOCIAL INNOVATIONS

Social sector innovations also pose risks: in private sectors many innovations fail and bring companies down with them. An innovation may also appear successful in the short term or bring benefits to an individual firm, but may have damaging social, economic or environmental consequences Bankruptcy cannot happen in the public sector but the consequences on the affected population in the case of failure can be even more dramatic.

HOW TO EVALUATE A SOCIAL INNOVATION?

In a certain way, innovation encounters difficulties because the social sector cannot judge them on a market/profit basis but on much more delicate parameters which are difficult to evaluate since they go beyond the technological answer of the solution, which is the case for long-term social and economic impacts.

RIGID NATURE OF AID RELATIONSHIP

A collaborative process is therefore a promising, and conceivably the only, possibility for the humanitarian sector to shift from an approach to innovation based on the incremental development of technologies already applied or the transfer of technology from fields which are borderline, to a more substantial approach in which innovation is leading. However, without a clear impulse in this direction "from the inside", any changes will be impossible.

---

[46] ALNAP, Ramalingam B., Scriven K. and Foley C. (2009 d) *8th review on humanitarian sector, Performance, impact and innovations*

FIG. 1.10: THE INNOVATIVE APPROACH OF SHELTER BOX

Questioning existing practices, norms, policies and rationale can often lead to direct conflict with ongoing organisational processes. Such "generative learning" is inhibited by a growing culture of compliance and the rigid contractual nature of aid relationships, both of which push agencies to deliver according to pre-defined goals, methods and targets. In response to this, and to the perception of continued learning failures, there are growing numbers of thinkers and practitioners within the sector who argue that agencies need to start pushing the boundaries of current humanitarian practice.

If established aid organisations fail to prioritise innovations, they are in danger of losing popular support and being overtaken by new types of relief organisations which are already coming into being[47].

1.5. Leading the innovation process and taking the risk

The humanitarian sector is at a crossroads: the latest developments in structural and material technologies, together with the expectations of donors and the increase in attention established by the spotlight of the media and public opinion, have forced NGOs to undertake a process to revise current processes and products which have not changed much over the last twenty years. This review process had already started in 2005 with the "Humanitarian Response Review" commissioned by OCHA.

RADICAL CHANGE OF APPROACH

Innovation processes have the potential to stimulate positive change: successful innovations can capture the humanitarian imagination and provide new ways of delivering assistance to those who need it most. A radical change in approach is required: instead of asking, "What went wrong?", and aiming for incremental improvements in delivery of aid based on current technologies, innovation requires new ways of thinking and the courage to look for more searching questions, such as "How are things currently done, and is this the best way to do them?"[48]. If the answer is no, then things should change and somebody must take responsibility for the consequences.

CLUSTER APPROACH

This needs to be done both at the shelter cluster[49] level and also within each NGO or authority leading the sheltering process in a particular area or case. Before the establishment of the Shelter cluster, as noted in the 2005 Humanitarian Response Review[50] which gave birth to the cluster approach[51] to address gaps and the effective strength of the humanitarian world, there was a general perception that the humanitarian response did not meet the requirements of an affected population and that the response provided varied

---

[47] www.shelterbox.org

[48] ALNAP Ramalingam B., Scriven K. and Foley C., (2009 d) *8th Review on the humanitarian sector: performance, impact, innovation, Chapter 3: Innovations in international humanitarian action.*

[49] The Shelter Cluster is co-chaired by IFRC and UNHCR at the global level. IFRC is convener of the Emergency Shelter Cluster in disaster situations while UNHCR leads the Emergency Shelter Cluster in the area of conflict generated IDPs. Additional information can be found at: https://www.sheltercluster.org

[50] UNOCHA,, (2005), *Humanitarian Response Review*, United nations, New York.

[51] IASC, (2006 b), *Guidance note on using the cluster approach to strengthen humanitarian response.*

considerably from crisis to crisis. Moreover, organisation and coordination among different entities were considered unsatisfactory.

This is the reason why clusters were established and nowadays the possibility of renewing and innovating in sheltering is clearly in the hands of the IFRC and UNHCR. But this is only the beginning of a long process which aims to change the mentality of the whole humanitarian sector, from the administration level to the volunteers.

Evidence from ALNAP's State of the Humanitarian System Report (2009)[52] and from other dedicated studies[53], suggests that ineffective leadership is still a major constraint to effective humanitarian action. Five main areas of leadership qualities emerged from the case studies of ALNAP

1) Strategic leadership skills in relation to the bigger picture;
2) Relational and communication qualities;
3) Decision-making and risk-taking skills;
4) Management and organisational skills;
5) Personal qualities;

INNOVATION ENTREPRENEURS

A number of motivated individuals work within and across different agencies in order to move ideas to wider implementation and diffusion. Of particular importance seems to be the presence and engagement of practitioners with extensive field experience who are then able to step back and look at the bigger picture. In each technology case, a leader has the role of establishing useful connections between a technological application in a different context. These same leaders could then play the role of "innovation entrepreneurs", championing the innovation process through mobilization of resources and people.
Why is it so difficult to lead and innovate in the sector? "The answer can be found in the uniqueness of the humanitarian context: working with people in distress, taking decisions that will affect lives and livelihoods on the basis of incomplete and ambiguous information, while under pressure to act rapidly"[54]. Moreover, people working in the field are part of bigger organisations which have their structure and hierarchy and, as a result, decisions which do not deal with the immediate response are demanded at the cluster level. Even if practitioners would like to adopt new methods - as was clearly shown in a survey presented by White and carried out by HFP[55] - how can one innovate when the immediacy of saving lives all too often prohibits creative and speculative thinking?

[52] ALNAP Taylor G. et al., (2012), *State of the humanitarian system 2012*
[53] ALNAP, (2011) Buchanan-Smith M., with Scriven K., *Leadership in Action: Leading Effectively in Humanitarian Operations*
[54] ALNAP, (2011) Buchanan-Smith M., with Scriven K., *Leadership in Action: Leading Effectively in Humanitarian Operations*
[5555] White, S (2008) *Turning ideas into action: innovation within the humanitarian sector.* A think tank for the HFP Stakeholders Forum. London: Humanitarian Futures Programme, p 3, Available at:

1.5.1. Leading innovation in the humanitarian sector

The leading of innovation in the humanitarian sector does not receive the attention it deserves and is mainly requested by chance. At least three players try to lead this process in the humanitarian sector nowadays, all of them with scarce results. These are: “experts”, “firms” and “NGOs”. The following chapters explain the reasons for their failure and why they cannot be “innovators”.

Experts

A comparatively small number of humanitarian aid workers remain in the field for their entire careers, which can leave relief organisations over-reliant on their small number of most experienced staff. Turnover of field personnel is high, which on the one hand can help spread innovation and bring a constant flow of new and fresh perspectives but, on the other, means that organisations lose accumulated knowledge.

INNOVATOR VS EXPERT

There is an interesting tension between the idea of the “innovator” and that of the “expert” which most of the time cannot coexist in the same person. Experts are asked to deal with an emergency and find the best possible solution in a short time. Incremental innovation usually arises from these people and some of their solutions are systematized and adopted by the sector. Innovators, conversely, are something more. They should primarily have the ability to look at the bigger picture and introduce innovations which cross different areas. Moreover, they should be able to learn from other fields, adopting and bringing new solutions into the humanitarian sector.

Firms

Industries knows that emergencies mean big markets in terms of volume and money and this is why there is interest in them. On the other hand, the barriers at the entrance are enormous and therefore new firms with innovative technologies have no chance of seeing their products applied in the field. Moreover, firms need to develop more sophisticated “radar systems” for detecting new ideas, capturing information from frontline deliverers, product-users and other external sources of innovation. They may need to support different kinds of players’ engagement with innovation processes; many firms are working with the end-users of their products as partners to make innovative improvements which deliver mutual benefits. The boundaries between a firm and its surrounding environment are becoming ever more porous. The theory and practice of innovation, originating from the private sector, is itself evolving, and has been adapted and reapplied to fit the different needs and realities of companies and entrepreneurs. Its relevance for humanitarian work is that it can help organisations focus on positive and proactive approaches to improve their work.

DETECTING NEW IDEAS FROM THE FRONTLINE

There are many examples of innovation and change in the humanitarian sector - beyond the idea of incremental learning from the past, and towards transformational learning for the future. But many organisations still do not have strategies to manage innovation, making it likely that many ideas are not picked up. A realistic understanding of what is possible can be complemented with learning from past innovations to seek new ways to realise improvements.

NGOs

BENEFICIARIES, NOT LEADER

Considered as organisations as a whole, NGOs are interested in better understanding the scope of innovations and bringing this knowledge into their organisations which can become more effective in the improvement of their work. But, as clearly stated, the innovation process is neither fixed nor linear, and depends greatly on the political and organisational context, as well as chance and luck. However, analysis of the development of innovations across different sectors shows that successful innovation processes are proactive intentional processes, include several common elements, and progress through a number of key developmental stages. Unfortunately, NGOs have no time for or expertise in managing these matters. This is the reason why they cannot be the leaders in this process. An additional problems derives from the decision-making process in such organisations which, as already mentioned in this dissertation, discourages innovation and risk-taking.

1.5.2. Taking the risk

To take a risk there must be a good reason, and there must be somebody who takes the responsibility for that choice. Finding good reasons is only possible far from the field where lack of time and resources does not allow occasions to investigate novelties. Incremental innovation, on the other hand, arises spontaneously when experts have to invent solutions with whatever scarce resources are available. But introducing an innovative attitude in the sector is a different matter.

Before applying any novelties at the level of the shelter cluster, the humanitarian sector requires clear answers to questions such as:

1) Why should a new variable be introduced in an already complex situation?
2) What are the clear advantages of a new solution compared to the state-of-the-art?
3) What is the risk linked to the new technology?

SAFE PLACES FOR EXPERIMENTS

In the second instance, a Plan B needs to be clearly identified. Before changing what is already tested and safe, an alternative has to be prepared in case of failure. In addition, the best scenario would be to reduce the risk by finding a safe and appropriate space for experimenting and testing in the field, close to the end-users, for example by starting from applying these solutions in a base camp or other services meant for volunteers instead of local people.

WHO TAKES THE RESPONSIBILITY?

Even if the efficiency and effectiveness of humanitarian sector actions have been put in doubt over the last few decades, not much progress in the systematic innovation process has occurred in the last few years. The analysis carried out by OCHA[56] clearly pointed out how the problem of "taking a risk" is one of the major stumbling blocks which affect the

[56] UNOCHA (2005) *Humanitarian response review,* United Nations, New York

humanitarian sector, while the same concept was investigated by recent studies of ALNAP in 2009.

Above all , the humanitarian sector is organized in a way in which decisions are demanded at a higher level of coordination, and coordination has to take into account the inputs from different organisations and match these with the already complex problem of the ongoing emergency. Thus decisions are commonly postponed or not taken at all.

The shelter cluster finds itself in this situation however some clear paths have already been traced out which clearly show the efforts made to innovate in the sector. This has been put into practice through the establishment of an SRU[57] which is in charge of investigating and validating the effectiveness of new solutions.

1.5.3. Recognition of problems and the opportunity to innovate.

The humanitarian sector is characterized by incremental innovation steered by "experts" and is based on punctual recognition of specific problems. Most of the time, this recognition is in response to a particular incident, predicament or systemic weakness. This recognition involves not just perceiving the problem but also re-framing it in a way which can lead to a process of seeking or creating possible solutions.

FORESEE AND AVOID PROBLEMS

An innovative attitude means foreseeing problems and avoiding them before they occur through different strategies either in terms of new products or processes. Unfortunately, it is well known that "in the eyes of many humanitarian practitioners, innovation refers to a commercial sector practice that takes place far from the emergency response challenges of distributing food rations, digging camp latrines and providing screening to under fives"[58]. But in the field, innovation has structural limits which would make it too lengthy compared to the opportunities and development of technologies now available, and if the goal of humanitarian aid is to do the best to alleviate suffering and address the needs of an affected population a clear revolution has to come about to turns ideas into action.

According to White[59], there are three main challenges to greater creative thinking and innovative practice within the humanitarian sector. These are identified as follows:

1) How can innovation be prioritized and identified within the sector? How is it possible to overcome obstacles?

2) How can innovative approaches be developed and tested within one's own organisation and operating network?

3) How does one create and sustain partnerships that foster innovation?

The following paragraphs try to provide answers to these questions.

---

[57] SRU: Shelter Research Unit

[58] White, S. (2008) *Turning ideas into action: innovation within the humanitarian sector*. A think piece for the HFP Stakeholders Forum. Humanitarian Futures Programme, London.

[59] Humanitarian future programme

1.6. Creative thinking and innovative practice in the humanitarian sector

TRUE INNOVATION

True innovations usually come out of the core of a business and not "incidentally" in a dedicated department which is supposed to somehow solve all problems with brilliant ideas. Most competitive companies and industries have the ability to understand that innovation involves the constant assessment of possibilities from many different sources and directions and take advantage from contrasts, for example low-tech vs. high-tech, external vs. internal, bottom up vs. top down. Making innovations correctly requires investment in a systemic innovation capability based on the building of an organisational architecture that is fully functional in this direction. Business experts note further that innovation rarely stems from a single individual, but instead grows out of a continuous exchange of ideas within and between collaborative networks[60]. Innovation, therefore, reflects a breakthrough moment on a continuum of incremental improvements brought about by months, and often years, of hard work and exchange of ideas.

The humanitarian sector, over the last few decades, has set the basis for a promising attitude towards innovation but it still usually misses the moment of shift. However, this author and many others, think that the time is ripe for change also in the humanitarian sector thanks to a clear vision of an innovative approach which identifies leaders, stimulates drivers, and would be able to screen, share and translate into actions useful inputs from other sectors and successful experience from the field.

Collaboration and the involvement of different partners with diverse skills and interests (from the social to the economic point of view) is the only way to reach the goals which, at the present time, present more obstacles than input.

1.6.1. Obstacles to innovation

Lack of time, lack of leadership, slow decision-making processes, a poor level of analysis of results and sharing of knowledge, lack of individual skills and the inflexible nature of large, slow-moving bureaucratic structures prevail as the major impediments to creative thinking and action[61].

LACK OF TIME

Lack of time is strictly related to the rigid structure of an organisation operating in the humanitarian field: the time slots for innovation are missing not only because people are primarily occupied with the contingency and the solving of everyday emergencies but also because things are done over and over again and, often, knowhow is not transferred and, is, therefore, lacking. Inter-organisation agencies have the role of smoothing this mechanism, but only relatively recently have successful results appeared.

---

[60] Berkum, S. (2007) *The Myths of Innovation*, O'Reilly Press, Sebastopol, Chapter 5.

[61] White, S. (2008) *Turning ideas into action: innovation within the humanitarian sector*. A think piece for the HFP Stakeholders Forum, Humanitarian Futures Programme, London.

LEADERSHIP

Leadership of the innovation process is somehow lost among NGOs, firms, and experts but, as highlighted in 2.4.1, none of these players can succeed in the role. A successful leader has to balance the interest of different players operating in the field while keeping the ultimate goal clearly in mind: i.e. improvement in the condition of the affected population in either a short- or long-term perspective. When players do not collaborate in this direction, conflicts arise which present a drawback for both the innovation process and, above all, for a general improvement in victims' conditions.

DECISION MAKING PROCESS

The decision-making process is the key factor which NGOs have struggled with for a long time. The USA's failures in response to Hurricane Katrina or some of the latest terrorist attacks clearly showed that decision-making in emergencies requires a non-traditional approach and tools characterized by a non-hierarchical structure and flexibility.

The dynamic environment of disasters makes it imperative to invest in inter-sector and inter-agency cooperation and coordination[62]. Traditional approaches characterized by hierarchy and centralization have been replaced by decentralized emergency management systems. The interactions of such multiple partners in emergency management has created new issues, especially in the phase of decision-making.

Collaborative decision-making can be defined as the combination and utilization of resources and management tools by several entities to achieve a common goal[63]. Because of the fact that emergency management is characterized by complexity, urgency, and uncertainty, it is crucial for participating organisations to have a fast but smooth and effective decision-making process, which is even more complex when different partners are involved at the same time.

Additional factors which influence the decision-making process are uncertainties caused by limited information on the situation, time pressure resulting from the urgency, stress caused by the importance of the decision and the assessment of risk linked to any decision. As stated in the previous paragraph, leadership becomes even more crucial.

REPORTING AND DATA ANALYSIS

Reporting on past works becomes useless without an effective method of knowledge transfer and data analysis to act as support for further development and help an organisation in its decision-making. The feeling is that, too many times, a previous analysis has not even been taken into account. The reasons are many: lack of information, difficulties in sharing knowledge and, sometimes, lack of trust in other institutions. Experiences (including failures) are, therefore, too often repeated in an innovation process which is much slower than it should be.

LACK OF INDIVIDUAL CAPACITIES

Lack of individual capacities reflects two different phenomena: on the one hand it is true that most practitioners are proactive and extremely willing to offer their contribution but they do not necessarily have technical skills or capability. As highlighted in the

---

62 Kapucu N., Garayev V., (2011) *Collaborative Decision-Making in Emergency and Disaster Management*, International Journal of Public Administration, 34: 366–375, Taylor & Francis Group, LLC

63 Turoff, M., White, C., Plotnick, L., & Hiltz, S. R. (2008). *Dynamic emergency response management for large scale decision making in extreme events*. Proceedings of the 5th International Information Systems for Crisis Response and Management (ISCRAM) Conference (pp. 462–470). Washington, DC: ISCRAM

introduction, sheltering is much more than just constructions and it includes various actions starting from logistics to transportation, planning and distribution, right up to the construction and management phases. It is clear that only some of the people involved can have a technical background, for example, in construction and building processes. Conversely, in an emergency, everybody is asked to give of their best even in areas which are not their own. This is a well known limit which can be reduced only in the long term but on which NGOs have been working for a long time trying to fill the gap in coordination and cohesion between standards, training courses, and the investments on offer from different entities.

On the other hand, it is essential to define just who is in charge of innovation and whether these people need to be identified within the sector. Unquestionably, a recent ELRHA study underlined one of the main problems regarding the sector: professionalization of humanitarian sectors so that they are seen as an internationally recognized humanitarian profession through the kind of coherent training and professional development that would normally be expected of any other established profession[64].

1.6.2. Effective partnership and contamination: the pillars of innovation in the humanitarian sector

FROM "CATASTROPHE-FIRST" TO "VULNERABILITY-FIRST"

A focus on innovation requires a different approach compared to the existing one: rather than only reacting after the event, the approach should be based on a shift from "catastrophe-first" innovation towards "vulnerability-first", focussing its attention on an increase in local ownership of humanitarian activities thanks to proactive work to prevent disasters.

To achieve this goal this author has identified two intimately linked strategies: the first is based on the collaborative method, the second refers to contamination from different fields, learning from experiences remote from the humanitarian. Both methodologies will be considered in depth in later chapters of this dissertation.

COLLABORATIVE METHOD

Concerning the first approach, it is clear that the humanitarian sector is not able (and does not want) to put an R&D core within the sector on the floor by itself, and this is why humanitarian agencies need to consider how to look for wider sources of expertise and ideas, from both inside and outside the sector.

While there are some examples of individual humanitarian organisations linking up with academics and private-sector companies to explore the development of a particular product, there is a considerable reason to look for greater cooperation. This needs to be done on the basis of competencies, mutual learning, and – probably the crucial factor – continuity.

Many innovations in the humanitarian sector have begun the process from recognition to development but then faltered or stalled – often for many years – before achieving wider implementation and diffusion. This is the case, for example, of the transitional shelter

---

[64] ELRHA, Walker P., Russ C., (2010) *Professionalising the Humanitarian Sector*, ELRHA.

FIG. 1.11: TS200 ONE OF THE SEVERAL DESIGN OF TRANSITIONAL SHELTER

approach which is an idea that first appeared in the 80s but never really broke through. Extensive work to understand how partnerships can build on the skills and capacities of different parties would be extremely useful in the humanitarian sector and would have relevance beyond innovation. The informal networks prevalent in the sector, but also official ones established for specific tasks and projects, could also support innovations more effectively.

For example, a partnership with a shelter provider in a relief context can be used to test new products, while also meeting physical needs. This could create a cadre of early adopters for this product. However, as already highlighted above, sustained R&D for new shelter solutions cannot take place during emergency contexts, but should use the experiences of the emergency to learn more about what can be applied. In this sense, the innovation agenda of relief has much in common with military R&D, and also requires a more strategic and considered approach to relationships in relief delivery, moving away from the model of "sub-contractors dedicated only to production" towards a new one of "partners for innovation".

SUB-CONTRACTORS VS PARTNERS FOR INNOVATION

In this respect, a more open attitude, especially regarding the definition of the requirements and products to be published in the emergency item catalogue would be helpful. As reported by ALNAP[65], practitioners usually "get contacted by [would-be shelter innovators] every week or every month. And they are often very insistent or very pushy. Normally, they have never actually met a refugee and never worked for a humanitarian organisation. But they have somehow found the answer that everyone else has missed for the past decade". This kind of approach, usually leads nowhere. On the one hand, the fact that NGOs act prudentially is fair enough. The reason is to avoid taking any decision under pressure from third parties which might put the accent on their interests which may not be the same as those of end-users. On the other, without knowing the real opportunities of the market and without letting third parties know what the exact needs are, how can industry put its knowledge and experience on the floor?

The result is the current static and slow-moving environment where innovations rarely arise. On the other hand, companies too have their rights: only if they were asked to participate in the knowledge sharing and decision-making process, might they take the risk to give away part of their knowledge (which could benefit competitors).

However, if benefits to the end-users is the ultimate goal, NGOs should be brave enough to open the discussion and, at the same time, stand proud. Industry, for its part, should take the risk to contribute, to end up as a "partner in innovation".

A large part of this discussion has been investigated and analyzed by the Humanitarian Innovation Project - HIF[66] of Oxford University, which aims to investigate emerging and under-researched ways in which innovation can be harnessed to improve humanitarian assistance. Thorough investigations in this direction have also been carried

---

[65] ALNAP, Ramalingam B., Scriven K. and Foley C. (2009 d) *8th review on humanitarian sector, Performance, impact and innovations*

[66] www.humanitarianinnovation.org

out by ELRHA which wishes to see a global humanitarian community where humanitarian players actively collaborate with higher education institutes to develop highly professional responders[67].

Considering the second approach, it must be taken into account that humanitarian relief can count on a large number of people who are not traditionally involved in the innovation process but who can provide their experience in terms of feedback and on-field experiences. Practitioners or "experts" for example, can offer their knowledge in this direction.

CONTAMINATION FROM DIFFERENT FIELDS

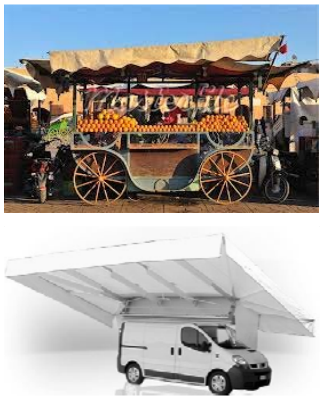


FIG. 1.12: DEVELOPMENT OF CARAVAN AWNING

This approach is certainly useful but stills remains within the range of closed models of innovation. Conversely, humanitarian sectors usually do not count on the support of players who are remote from the field but would like, for several reasons, to have the possibility to contribute with their characteristics and skills.

This is the case of the world of lightweight construction in general which is in contrast with traditional building construction but finds widespread application in different fields such as leisure, temporary events, sports, but also hobbies and DIY. All of these worlds could offer a series of precious inputs which, through different processes (adaptation, downgrading, etc.) could be transposed and applied in the humanitarian sector.

One of the most intuitive examples is the building of a small roof which can benefit from inputs from the smart and efficient world open market. High-tech automatic awning systems for caravans have been developed starting from the ancient awnings of stands and trailers.

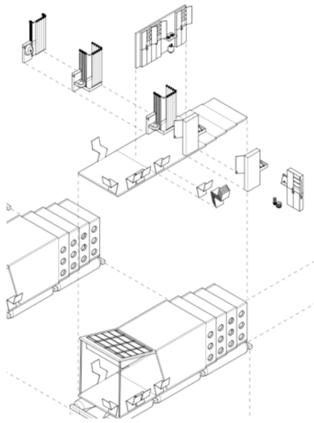


FIG. 1.3: SETTING-UP PROCESS OF S.H.R.I.M.P.

A second example could come out of the IKEA approach, which is, at the present time, looking with interest at the world of sheltering[68]. Easy to assemble and stock prefabricated systems which can be mounted by end-users have made IKEA one of the most profitable companies currently on the market. Is it possible to apply the same principle that has radically innovated the world of furniture and its design to the world of sheltering? This has already cropped up with the design known as S.H.R.I.M.P. – Sustainable Housing for Refugees via Mass Production by Vestal Design[69] in which the roof and walls are connected as easily as building a bookcase. Modularity has also been considered a key feature in this approach which is something that is usually difficult to find in current sheltering solutions (see Chapter four).

[67] www.elrha.org/about

[68] pages.ikeafoundation.org

[69] www.vestaldesign.com/projects/refugee-housing.html

1.7. Conclusions

"The challenges the humanitarian community encountered last year in Haiti and Pakistan clearly demonstrate that it urgently needs new knowledge, new expertise and new approaches. At the same time, there is a growing expectation that decision-making and programme design by humanitarian agencies should be evidence based. However, the pressures on today's humanitarian practitioners to deliver assistance at great speed and often to predefined goals, methods and targets provide little space for analysis, reflection and investigation. As a result, there is a division within the humanitarian community between those who are employed to "think" and those who are employed to "do". This limits our potential to be truly responsive to humanitarian crises."[70] *(Camburn J., director of ELRHA)*

BRIDGING THEORY AND PRACTICE

Bridging theory and practice is the key to succeed as an innovator in the humanitarian sector. As noted in a recent report by OCHA, in the past 25 years… "innovations in post-disaster shelter and housing have been limited"[71]. This finding stands in stark contrast to the huge number of product innovations presenting "solutions" to the problem of emergency shelter over the same period that never entered the market.

In the 1980s and early 1990s, as agencies got bigger and humanitarian case loads grew, the capacity to improve response-preparedness increased. This led to several process innovations such as stockpiling goods in strategic locations, the organisation of pre-made kits and service packs and, if required, the staff to manage them, preparation of emergency-staff roster systems at international and regional levels in order to strengthen surge capacity, definition of risk assessment and contingency planning tools for certain scenarios[72].

PROCESS INNOVATION VS PRODUCT INNOVATION

On the other hand, product innovations have encountered many more obstacles and their introduction to the market has been much slower. Innovation in its truest form is not about a particular product but about a way that an organisation or company operates, continually seeking and assessing possibilities from a variety of sources. As Davis stated in 1978[73], "shelter must be considered as a process, not as an object". Products, therefore, have generally been considered secondary even where renovation was necessary. However, this author thinks that focus on products should also have its dignity. Development in

---

[70] ELRHA (2011), *Guide to constructing effective partnerships*

[71] OCHA (2006) *Exploring key changes and developments in post disaster settlement, shelter and housing*, 1982 - 2006

[72] ALNAP, Proudlock K. and Ramalingam B. with Sandison P., (2009 c) *8th review on the humanitarian sector, Improving humanitarian impact assessment: bridging theory and practice*

[73] UNDRO (1982*), Shelter after Disaster: Guidelines for Assistance*. United Nations, New York.

materials is only one of the several reasons forcing the renovation of products which can now offer a level of performance unthinkable even ten years ago.

LOOK AROUND

The humanitarian sector has finally realized that "looking inside" is not the way to come up with true innovation in the field; conversely, the humanitarian sector needs to be ready to "look around". In fact, a sector-wide mechanism to promote and facilitate innovation is missing within the established institution. Innovation intermediaries have been successfully used by private-sector companies and increasingly also by non-profit organisations, but there is currently no organisation taking this role in the humanitarian sector. Effective partnerships are, therefore, the answer, and a stable and structured process of establishing "partners of innovation" could produce faster than expected results.

PARTNERSHIP

Partnership has been highlighted as the key factor to renovate the sector[74]. Collaboration has to be considered within a large spectrum and, therefore in respect to recipients and organisations, between national and international agencies, with researchers and academics, with the private sector, between donors and implementers, and between agencies.

CAPACITIES

On the other hand, the humanitarian sector should be able to enhance capacities which are currently weak within the players: entrepreneurship and leadership. Practitioners and experts, researchers and evaluators should build a solid base on which new and "external" capacities can flourish. Contamination from other sectors traces out a clear path here.

"Vulnerability-first" oriented innovation would also reduce the major obstacles to novelties: people's lives and livelihoods can depend on receiving aid of the right type and quantity, in the right place, on time.

HONOURABLE RISK

There may well be space to encourage greater innovation in aid delivery, without compromising ethical principles or taking risks with lives and livelihoods. But the central question is how to create a culture of "honourable risk" in humanitarian work. By definition, innovation requires new ways of thinking and new approaches to practice. At the same time, innovation faces a high risk of failure but can create new opportunities by doing things previously thought impossible.

SAFE SPACES FOR EXPERIMENTATION

Finding safe spaces for experimentation and mechanisms to promote "honourable risk" as a central value in humanitarian assistance is perhaps the first step to a more innovative and yet principled humanitarian response. The challenge to non-commercial innovation is to innovate in the face of complex and ambiguous rules, multiple conflicting interests of diverse stakeholders, and a variety of resource, operational and ethical constraints. The key here is to ensure minimum standards and allow innovations which at least meet these standards while improving on performance in key areas without causing additional or unanticipated problems or costs.

DISPLEASURE REGARDING HUMANITARIAN AID

Some commentators have claimed that humanitarian aid has entered a period of crisis since there is widespread cynicism in Western countries about its effectiveness, fed by a steady stream of negative media stories[75]. Humanitarian workers themselves are amongst

---

[74] UNOCHA. (2007), *The Four Pillars of Humanitarian Reform*, New York.

[75] Rieff, D., (2002), *A Bed for the Night: Humanitarianism in Crisis*. Vintage, New York.

the harshest critics of the current system. But there is also good work in progress and positive changes underway.

As Hugo Slim[76] argues, any view of the sector needs to be set in the context of the political expectations of what we believe "international society" can achieve in the humanitarian sphere. This initial exploration leads us to believe that a pragmatic view of the potential of innovations in the sector is perhaps the most useful one.

DEFINITION OF A CLEAR STRATEGY

The system needs to identify the things it really can change and the softer border points where it can push these limits over the coming years. Many of the things that can be changed will be inner-realm organisational things which have already been identified, such as knowledge, expertise, capacity, effectiveness, efficiency, accountability. In terms of innovation, effective partnership and contamination from other fields will drive "new and fresh air" into the sector.

The challenge to change the humanitarian sector is to innovate in the face of complex and ambiguous rules, multiple conflicting interests of diverse stakeholders, and a variety of resource, operational and ethical constraints. The emerging framework of innovation in this field is complex and includes different factors which this author has tried to present in this chapter. The road is long but the future of the sectors will depend on an ability to turn all these ideas into actions.

[76] ALNAP, Slim, H.,(2006), *"Global welfare: A realistic expectation for the international humanitarian system?"* in ALNAP Review on Humanitarian Action: Evaluation Utilization. London: Overseas Development Institute.

2 SHELTERING: TARGETING AND ADDRESSING THE PROBLEM

Sheltering is the typical example of a complex problem where actors and variables of different kinds enter the process with different interests and at different levels and time. As presented in Chapter one, this congestion of actors and interests is one of the main reason for the difficulties of emerging innovation which arise on a daily basis but are rarely systematized. Actors in the process of sheltering are NGOs with their practitioners, local authorities, donors and we must never forget, victims. If old theories of humanitarian assistance saw the latter passive spectator of the process of sheltering organized by international or local agencies, the latest approaches focus more on the involvement of victims from the very beginning of the relief phase with the aim of strengthening ownership through participation in the process of developing and, sometimes, of decision-making too.

CONGESTION OF ACTORS

The process of sheltering is, therefore based on variables which are related to the emergency itself, such as the type of disaster (e.g. natural, like earthquake or flood, but also human, like war), its magnitude and its duration. Other variables derives from the location where the disaster occurred: cultural, religious and social background influence strongly the process of sheltering as much as the economic background which contributes to the level of resilience of a particular area.

VARIABLES

If, on one hand, the very first phase after an emergency strikes is probably similar to another emergency, as soon as lives have been saved, every reconstruction project becomes unique. The nature and magnitude of the disaster, the country and the institutional context, the level of urbanization but also the diffusion of education and the cultural values all influence decisions on how to manage reconstruction. Whether a government uses special or normal procurement procedures, how it weighs the concerns of speed versus their quality, and what it considers the proper institutional set-up and division of labour will

UNIQUENESS OF AN EMERGENCY

also vary. History and best practices are simply evidence to be weighed up in arriving at the best local approach[1] *which can rarely be foreseen.*

2.1. Product development of sheltering

An effective sheltering program should take into consideration all these variables and therefore, the questions arise spontaneously: how is it possible to address specific answers to different catastrophes without knowing most of the variables involved? How can humanitarian aid organize the immediate response in a matter of hours keeping in mind the bigger picture? Is this noble goal supported by technologies, tools and products currently in use in the humanitarian sector or are those tools perhaps limiting the range of action?

UNIQUE ANSWER WITH STANDARD TOOLS

Current relief is based on tools which are standardized and listed in catalogues and can be selected according to necessity. Unfortunately, the degree of flexibility of these solutions is, most of the time, limited, even if kits are becoming more and more popular. NGOs have on their shoulders responsibility for the application of particular solutions that will strongly influence the living conditions and development of a community for an undefined period which can be of one or two months, but also years.

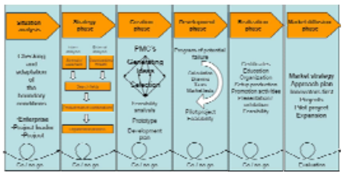


FIG. 2.1: PRODUCT DEVELOPMENT PHASES BY JOS LICHTENBERG

If it is true that the perfect shelter refers to a vernacular architecture that takes as inspiration the specificity of the context in which it has to operate, then it cannot be standardized and applied in different scenarios and therefore it will never appear in the catalogues.

On the other hand, a progressive solution based on standard elements which can be combined differently according to the contests they are applied in, might, in some way, provide an answer to a search for the most suitable solution (see part II).

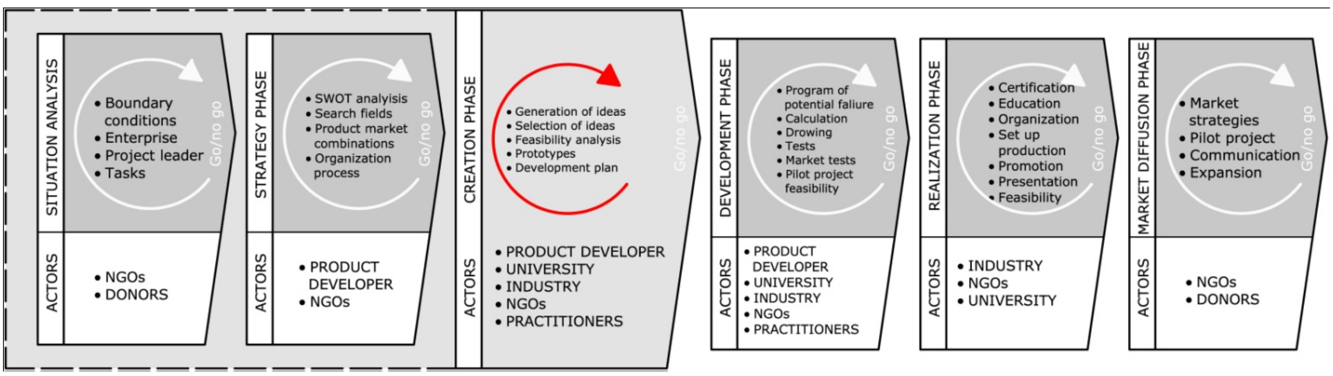


FIG. 2.2: PRODUCT DEVELOPMENT PROCESS: ADAPTATION TO THE CASE OF EMERGENCY SECTOR

[1] World Bank, (2010), *Safer Homes, Stronger Communities, A Handbook for Reconstructing after Natural Disasters,* The World Bank, Washington DC

CENTRALITY OF THE "CREATION PHASE"

In this liquid scenario the definition of precise requirements, the identification of all boundary conditions, and the selection of the appropriate approach in advance are not reasonable and sometimes, not even the best way towards the fastest development of the affected community. On the contrary, the advanced capability of identifying habits and foreseeing requirements by learning from the field is probably more useful.

Starting from the theory of product development typical of building construction but, in general of industry, in the special case of the humanitarian sector, the "creation phase" enlarges its influence by embracing the analysis and strategy phases too. The limitation of a linear and rigid "go/no-go" process could fail in two ways: firstly by offering a solution that matches boundaries and requirements that do not follow users' demands; secondly it can "entrap" the process which may be applied when it is already old, without having to shift its focus onto new demands which are "ongoing".

RISKS OF LINEAR PROCESS

Therefore, this author thinks that, to really succeed in offering an effective process of sheltering, situational analysis and strategy phases should be considered part of the creative phase which needs inputs from different actors (product developer, NGOs, practitioners form the field, industries, universities) and keep boundary conditions open because new ideas can generate new demands or modify priorities which have to be changed.

CENTRALITY OF THE CREATION PHASE

The following paragraphs will try to analyse these aspects and will highlight the limits of the current strategies, opening the road to possible alternatives keeping in mind the major risk of this approach: namely, getting lost in an endless process of variation and combination which neutralize its potential.

2.2. Boundary conditions: mapping

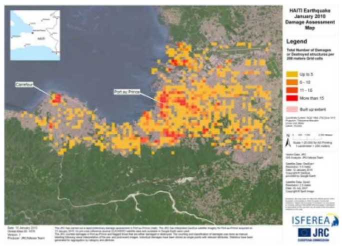


FIG. 2.3: HAITI EARTHQUAKE 2010 DAMAGE ASSESSMENT MAP

A process of mapping is adapted to systematize the complexity of the factors which may influence the success of a sheltering process in a specific area. Nowadays, large and exhaustive databases[2,3] have been set up and are able to offer an endless amount of information about countries affected by hazard even in real time[4]. These tools, together with

2 hdr.undp.org: collecting the Human Development Reports, a source of precious information about any developing country

3 www.emergencyresponse.eu, Global Monitoring for Environment and Security (GMES) is a European programme led by the European Union and implemented by the European Commission (EC) jointly with the European Space Agency (ESA). It is aimed at developing a European information service based on satellite Earth Observation and in situ (ground based) data. The objective of GMES is to monitor and forecast the state of the environment on land, sea and in the atmosphere, to support the security of every citizen as well as the emergency services. The information provided by GMES aims to improve people's safety, e.g. by providing information on natural disasters such as forest fires or floods, and thus help to prevent the loss of lives and property

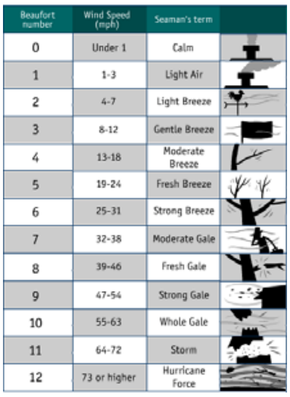
4 reliefweb.int: ReliefWeb is a specialised digital service of the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) that provides reliable disaster and crisis updates and analysis to humanitarians, so they can make informed decisions and plan effective responses. The Reliefweb has three main functions: collecting updates from all over the world 24/7; presenting the most relevant content to the audience; provide specific countries overview and disaster updates

the implementation of GIS- Geographic Information System software (even based on popular mapping tools like Google earth[5] or linked to social media[6]) in the humanitarian sector are able to support the humanitarian response both in an emergency but also in the preparedness phase.

This thesis does not want to limit the importance of mapping but does want to stress the importance of a careful and specific decision making tool based on contingency rather than a long list of data which may be taken the wrong way. The importance of local delegates is therefore crucial since they are the only ones able to read these data and understand their meaning, translating them into design inputs.

The dream of being able to scan and synthesize in lines of tables the complicity of the most vulnerable areas on earth may be tricky and even counter-productive for several reasons.

If, on one hand, climate data are extremely useful and, nowadays, relatively easy to collect precisely, more specific data regarding, for example, cultural habits, material resources or production capabilities are much more difficult to sort out.



Beaufort number	Wind Speed (mph)	Seaman's term	
0	Under 1	Calm	
1	1-3	Light Air	
2	4-7	Light Breeze	
3	8-12	Gentle Breeze	
4	13-18	Moderate Breeze	
5	19-24	Fresh Breeze	
6	25-31	Strong Breeze	
7	32-38	Moderate Gale	
8	39-46	Fresh Gale	
9	47-54	Strong Gale	
10	55-63	Whole Gale	
11	64-72	Storm	
12	73 or higher	Hurricane Force	

FIG. 2.4: CALCULATION OF WIND LOADS: THE BEAUFORT SCALE

First of all, data must be updated often because its context might be in continuous evolution especially in regions under development or often affected by crises.

Secondly, surveys may require time and money and do not always assure effective results. In addition, these amounts of data may turn into something difficult to access due to their complexity while a synthesis of them may turn into a poor and pointless simplification which does not help much, or may even provide incorrect inputs.

As presented by Dr. Purnima Chattopadhayay-Dutt, German Red Cross Delegate in Bangladesh, writing about people living in cyclone-prone areas, instead of considered the population passive and trying to offer them a "Western solution" to a natural phenomena which is typical of that area, "there might be any existing coping mechanisms, which we do not know of, but on which we could build our interventions in a more sustainable way"[7].

It is clear how, even with all the efforts of the donors, only a limited number of people can be provided with houses, which might not even meet their individual needs because of their uniform layout. But if we can identify indigenous techniques of cyclone-strengthening of houses, and combine these with the findings of modern architectural technology, we might actually be able to contribute towards a mitigation of the destruction of houses. We cannot stop cyclones from coming but we can try to strengthen the self-help capacity of people to cope with the disaster in a more sustainable way.

This is why mapping should look more closely at vernacular habits of building construction, instead of trying to categorize and forecast phenomena which are by definition difficult to predict: the result should stimulate the development of a flexible

[5] www.mapaction.org: NGO operating in the sector offering help to volunteers and victims right after the disaster in form of maps

[6] esriaustralia.com.au, TSC social media team

[7] Haq B., Chattopadhayay-Dutt P. (2007), *Battling the storm, study on cyclone resistant housing*, German Red Cross, Bangladesh

approach able to merge inputs from the contingency, while remaining adaptable and implementable according to each situation.

2.3. Requirements

Every design and/or product development usually starts from a definition of the requirements expected, based on the demands of the clients or needs of the end users together with the verification of accordance with regulations and standards, either at a local or international level.

In the specific field of architecture, these requirements are crucial, for example, to define the general layout and clearly set the required building performances. When design becomes complex, it can sometimes happen that these requirements become difficult to list: it may be that some needs are in contrast with others or that new additional demands appear only when the process has already started.

In the case of humanitarian application, the framework become even more complex. First of all, "clients" and "end users" are not known in advance. This is the area which "emergency preparedness" and "mapping" should work on.

Based on past experience, NGOs try to represent at the same time both the purchaser of the sheltering solution and their end users, with an evident conflict which is difficult to solve. In addition, boundary conditions are unknown. Thirdly, the timeline is not fixed nor linear; on the contrary it can be liquid, a new emergency could arise and the priorities change: a definition of priorities in an emergency must be kept as open as possible.

For all these reasons, requirements in an emergency are much more dynamic than in any other case. In addition, it has to be highlighted that the demand side can rarely organize needs and provide information at once. Even after years of experience, only lately has an attempt been made to organize this knowhow in a way that it can be used in practice for future emergencies.

CENTRALITY OF THE CREATION PHASE

Until now, the experience of NGOs has arisen from collaboration with a large number of practitioners over time who have built up their own specific experience and expertise in different circumstances. Therefore, it is hard to expect that anybody is by him- or herself capable of coming up with a complete range of requirements with a general overview because the result will always be based on individual experiences.

Work in clusters[8] aims to shift and organize the knowhow in a way to substantially support decision of NGOs. At the present time, they are the only actors able to identify

[8] The concept of "cluster approach" was an outcome of the Humanitarian Reform process in 2005 which was led by the Inter-Agency Standing Committee (IASC) comprising NGO consortia, Red Cross and Red Crescent Movement, IOM, World Bank, and United Nations agencies. The reform identified three axes, known as the three pillars of the reform. They are: 1) development of clusters at global and country levels; 2) strengthening of the role of the Humanitarian coordinator at field level; 3) and modification of some aspects of the funding mechanisms.
These three pillars rely on the principle of strengthening partnerships between all actors as the key to improved coordination. Detailed information may be found at www.icva.ch/ngosandhumanitarianreform.html for example in

requirements, however their view it is often partial and they sometimes lack a technical background. On the contrary, requirements should be identified through a reverse process and mainly arise on the way in a process of adaptive learning in a situation totally in contrast with the strict and fixed definition of boundary conditions.

How is it possible to find an alternative to this approach which could also speed up the process of innovation? Bottom up and top down approaches have to coexist to offer the best trade-off.

DEFINITION OF THE DESIGN LOAD

If we are talking, for example, about the identification of the design load for an emergency shelter, a structure designed according to snow and wind load regulations meant for building which has to last for 25-50 years, would never meet the requirements of light weight or reduction in cost. However, return periods of worst scenarios heavily influence the design of wind load to be applied in a structure meant be erected for few months. And this is the same for snow: would it not be reasonable to consider that owner or practitioners should be able to clean their roof of snow, when needed?

It is evident the debate on this topic cannot be threaded into a few paragraphs and may require a dedicated dissertation linking the technical background with emergency management able to examine in-depth areas such as leadership, responsibility and risk in humanitarian intervention.

2.3.1. From requirements to users

Instead of struggling over numbers, safety factors and statistical coefficients which will rarely match the specificity of the emergency phases, the sheltering process should focus on the end users who are not the NGOs but the victims.

The role of NGOs is to represent victims and give voice to their needs which might be difficult to identify and evolve according to the emergency phases. For these reasons, periodically, a series of standards are agreed by the humanitarian community with the aim of increasing the life quality of the affected population.

Standards differ according to the location of the disaster and the development of the community affected. Sheltering people from third world counties is very different from operating after a disaster in the U.S. The same shelter system in the hands of NGOs might be applied as a hospital in third world countries and as a family shelter in Europe. On the contrary, the family shelters used in third world countries are not deployed in Europe at all.

Among the best known publications about standards of shelter one should refer to "Tents, a guide to the use and logistics of family tents in humanitarian relief"[9] and the "Sphere Project handbook"[10], which are both based mainly on the living habits and conditions of developing countries.

"Synthesis Report Review of the engagement of NGOs with the humanitarian reform process" or at www.sheltercluster.org

[9] UNOCHA, (2004), *Tents: a guide to the use and logistics of family tents in humanitarian relief,* UN publications

[10] Sphere project, The (2011), *The Sphere Handbook: Humanitarian Charter and Minimum Standards in the humanitarian Response,* Geneva.

2.4. Lightweight textile constructions: a possible answer

FIG. 2.5: LOUISE BOURGEOIS SPIDER SCULPTURE

The application of lightweight textile systems matches the requirements of a controlled and standardized solution able to interact and change configuration relatively easily and rapidly (compared with heavier technologies) according to the context. Lightweight constructions are able to fill the gap left by standard construction methods which are surpassed in terms of efficiency, velocity and cost/benefit ratio.

Textile architecture is, traditionally, the answer in the event of an emergency (e.g. after a natural disaster or war), when easy-to-transport and fast assembly solutions are required to house and shelter people in need.

Over the last fifty years, engineers, architects and designers have focused their attention on the design and construction of innovative structures which combines the beauty of tectonics with the efficiency of the structural principles behind them, as clearly shown in the works of F. Otto, B. Fuller and other architects, engineers and artists and neatly summarized in the literature[11].

Amazing structures, together with visionary concepts, became icons of a particular kind of architecture which differs greatly from the massive and monumental constructions of the past.

On the contrary, ephemeral architecture has become synonymous of efficient, smart and also sustainable construction systems for the future. Sustainability in terms of "lightly touch of ground" as in Murcutt's words[12] but also regarding the material saving and reduction to the essential, the minimum[13].

In addition, a piece of architecture can be considered sustainable when it can be adapted over time or be dismantled and re-assembled where and when required[14][15]. All these characteristics bring lightweight architecture closer to the world of industry, where production processes are controlled and optimized, compared to the traditional sector of building construction where the phase of construction is the most relevant one.

PRODUCTS OF ARCHITECTURE

Application of lightweight architecture in the event of an emergency, for example, after a natural disaster or during conflicts, is, therefore, ideal. Shelters are inserted in the emergency items catalogue and can be purchased all over the world with quality certifications.

---

[11] Kronenburg R., (2000), *Portable Architecture*, Architectural Press, Oxford. and Kronenburg R. (2005) *Houses in motion, the genesis, history and development of portable building*, academy Editions, London.

[12] Drew P., Murcutt G. (2000) *Touch this earth lightly: Glenn Murcutt in his own words*, Duffy & Snellgrove

[13] Otto F. (2004), *On the Way to an Architecture of the Minimal*, in "Brian Forster", Marijke Mollaert (eds), *European Design Guide for Tensile Surface Structures*, TensiNet, Brussel.

[14] Zanelli A., (2003) *Trasportabile trasformabile : idee e tecniche per architetture in movimento*, CLUP, Milano

[15] Giurdanella V, Zanelli A., (2010) *Temporary building intended as adaptable and reversible building: a sustainable strategy for housing – The recent situation in Italy*.

Standardization of solutions has enormous advantages in the complex world of humanitarian aid where practitioners do not always have a building construction background and solutions have to guarantee the abovementioned minimum standards.

On the other hand, innovation regarding these kinds of structure in an emergency is stuck. Promising and radically innovative solutions cannot contribute to the field which goes for standard products forgetting that a perfect shelter does not exist while the integration with vernacular construction methods, materials and tradition would be the only answer.

The result is that, at the present time, lightweight architecture has evolved and reached a high level of technology while emergency solutions have remained the same for decades.

2.5. Lightweight textile structures and emergency: advantages and drawbacks

It is evident that products like tents or fabrics of different kinds and weights are massively distributed in emergencies. For sure, the humanitarian sector requires an efficient and rapid deployable solution but this does not mean that all these kinds of structure have entered the sector.

NOT JUST A MATTER OF WEIGHT

If we are talking about structures which are lightweight only in terms of "weight", a lot of examples could be listed. On the other hand, many even lighter structures based, for example, on foldable or expandable principles have never been applied in emergencies.

Nonetheless, many projects and prototypes have been produced by industries and researchers. Lightweight and ultra-lightweight constructions give of their best when they have to be applied in the event of a lack of time for set-up and when transportation is an issue.

Why have these kinds of structures not been applied more often in emergency situations? This author believes that, by and large, a distrust of lightweight structures comes from a lack of knowledge. Architects, engineers, but also volunteers and the general public are not used to dealing with the new principles that lightweight architecture offers. In front of such a kind of structure, people are astonished and impressed, however, these structures are far from being generally accepted in everyday life.

In addition, sometimes in the past, lightweight systems have been presented as the easiest answer on too many occasions. The utopias of the 70s and 80s fascinated architects and engineers but, at that time, technical solutions and materials were not able to ensure high performance for these futuristic designs.

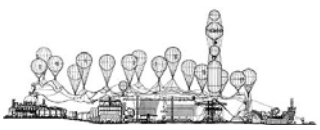


FIG. 2.6: INSTANT CITY, ARCHIGRAM

Starting from the tremendous gap between the design and the final product, the belief in a sustainable, fast, transportable, flexible living environment disappeared. People still have in mind early experiments in which the dream of lightness and innovation was not fulfilled at all. Moreover, the appeal of those structures was far from the beauty of the designs and concepts developed at that time.

MATERIAL AND TECHNICAL DEVELOPMENT

On the other hand, in the last twenty years, material science developments and the constant transfer of knowledge, for example, from the sailing and sports industries to architecture, have offered better and lighter materials with higher performance from every point of view. As a result, nowadays, new systems, technologies and solutions are available which, in most cases, have overcome the old limits.

However, the risk of going too far must be avoided: especially in the event of an emergency, solutions must fulfil strict standards and rules and reliability remains the main pillar.

Sometimes lightweight constructions perform well, other times they do not. The worst mistake would be to push one technology when it is not ready, or if there is no reason to apply it. This is why there are so many differences between temporary solutions "by choice" and ones that can be applied "in an emergency". However, contamination is possible and would benefit the humanitarian sector as a whole.

The goal of this paragraph is to see whether some lightweight technologies are ready to provide their benefits in humanitarian relief too. Below is a list of possible advantages and drawbacks when applying lightweight textile structures in the event of an emergency. They have been divided into macro areas.

Application of lightweight technology in emergency

Advantages	**Disadvantages**
Set-up	***Structural limits***
1. Lightness 2. Transportability 3. Fast to built/dismantle 4. Self-scaffolding 5. Simple material/elements involved	1. Safety doubts/risk 2. Limited/low load bearing capacity 3. Stability 4. Weak connection and details 5. Durability of parts
Usability	***Control of internal comfort***
6. Adaptability/modularity 7. Appeal 8. Visible and distinct structures 9. Easy to process and integrate with local materials 10. Second/ third use, recycling possible	6. Low thermal insulation 7. Low acoustic insulation ***Design and layouts*** 8. Design required 9. Restrictions on shape ***Acceptance*** 10. Specific knowhow for setting-up and repairing 11. Social acceptance of shapes and materials

ADVANTAGES

The advantages of the application of lightweight textile architecture in an emergency are clear also for people who are not from the sector. Lightweight constructions clearly show features that match the requirements to be applied in post-disaster situations. The advantages presented are specific to textile constructions and are of great benefit in the emergency field. They can be sorted into two main areas:

1) advantages related to the very first phase (the set-up) and
2) advantages related to the life cycle of those systems (usability).

The first category of advantages is strictly connected with the rapidity of the setting-up phase: the faster the better, but keeping in mind the quality of the product and its life cycle. These aspects will be presented in Chapters 3-4 and 5 of this dissertation. From the second category, two main advantages rely on the possibility to implement the basic structure with local materials (point 9) which will be largely discussed in Chapter 6 and the opportunity to reuse those structures for a second or third purpose (point 10), when the emergency has passed which will be presented in Chapter 7. This list of advantages will be kept as the background of the product development will be presented in part II.

DISADVANTAGES

On the other hand, the list of disadvantages must be carefully addressed and investigated because they have been the main driver of this research. Most of the disadvantages listed above affect traditional structures too, but they have peculiarities which derive from the intrinsic characteristics of lightweight systems.

They can be divided into four main areas: 1) structural limits; 2) control of internal comfort; 3) design and form problems; and 4) acceptance of the technology provided. These topics will be analysed separately below.

COSTS ANALYSIS

The topic of cost has not been identified in this list quite deliberately either as a pro or a con. It is well known that any solution should offer the highest performance at a reasonable cost. Cost-benefit ratio is the main indicator, in the end, to evaluate the feasibility of a sheltering project. Structures meant to be distributed in hundreds of thousands of pieces and then disposed/recycled have a certain target price, whereas reusable structures for logistic or health have different ones.

No solution can be taken into consideration without a detailed cost analysis which not only involves the amount of materials but also the costs in terms of shipment (volume, weight) and, most importantly, in terms of delivery time. Comparison of a more expensive system with a second one which requires 20% more time or labour force for construction has to be addressed and might "cost" a lot.

In the end, the choice will depend on the phase of the emergency when it will be applied (in the very beginning rapidity is essential while in a later stage this could become secondary). As a consequence, generally speaking, a detailed analysis of costs does not make any sense, therefore a deeper analysis will be presented as a consequence of the product design developed in Part II.

2.5.1. Structural limits

Public opinion considers lightweight and special structures unsafe. This is a general attitude that comes from a lack of knowledge about the behaviour of these structures under loading.

Tensile structures are as safe as traditional ones and, sometimes, even more so; in the event of collapsing, for example, large deformations appear in advance, clearly indicating potential risk (this is definitely the case of pneumatic structures, for example, if overpressure decreases). Moreover, the weight of a single element is usually not dangerous for its guests even if they are beneath the structure at the moment of the collapse.

However, their rigidity is much lower compared to traditional systems and this is why shivering and other movements are present in a strong wind: this is something people need to get used to.

Membranes or other fabric elements are considered weak points. This is only true in cases where the membrane collaborates in the stability of the whole system: in these cases, if any element breaks (not only the fabric but cables or struts too), the stability of the whole system is endangered. Nevertheless, the textiles in use in general practice are generally several times more resistant than the load bearing structure itself (e.g. poles, cables...) therefore problems of this kind are minimal.

NATURAL AND HUMAN FACTORS

Collapsing of structures can be sorted into two macro areas: collapsing due to natural factors (e.g. wind or earthquakes) or human factors (e.g. design errors, attacks or vandalism). In the first case, the whole structure collaborates in contrasting the external forces. A first-class design of shapes and details and good manufacturing can produce, for example, tents that are able to withstand incredibly heavy wind loads. Current knowledge and the materials available have lowered this risk of collapse.

As regards human factors, design errors are possible, but rare. They appear when unpredictable loading conditions arise or when information is lacking (for example experience of soil composition).

FIG. 2.7: GUY ROPES TO STABILIZE INFLATABLE TENTS

As for vandalism or attacks, these are certainly a problem that has to be solved in the design phase. Fabrics and cables are considered the weakest points because of their thin section. However fabric can be punctured or cut only after heavy contact with sharp elements: it is extremely rare that this could happen accidentally. In the worst cases, a small cut (10-20cm) in fabric does not mean that the structure will collapse: in the case of pneumatic structures, the systems are usually designed to compensate for loss of air by means of an air-pump. In addition, tensile membranes are designed to avoid tear propagation.

In the case of cables, these are, most of the time, made of steel: special pliers are required to cut them. However, vandalism should be taken into consideration by avoiding direct contact of people with the weakest points of the structure. As the reader may notice, this is difficult and, sometimes, impossible.

Limited bearing capacity must also be addressed. Lightweight and especially temporary structures are systems designed to match specific loading criteria rather than, as in architecture in general, to resist the worst possible conditions which may only happen once in their lifetime.

To obtain a high level of bearing capacity with lightweight structures is possible but, most of the time there is no reason for it. High bearing capacity means unreasonably higher stresses (or higher pressure in the case of inflatable) which lead to bigger section of materials and/or a bigger mass (in the case of foundations, for example). Moreover, higher risks of failure or damage subsist if forces are intense.

OPTIMUM DESIGN

The best design is one that calibrates forces within the structure to satisfy safety standards along with sustainable use of materials, and redundancies. In the case of application in an emergency definition of the design load is crucial. Building regulations give guidelines on how to calculate design load based on location of the building (risk, wind and snow load), the kinds of activity which they have to host and the expected lifetime [1]. Definition of these inputs is crucial to find the best trade off between structural integrity and costs. Debate is still going on here due to open questions about the responsibility for taking this kind of decision (e.g. lowering the return period) as we saw in Chapter 1.

Connections and details can be weak points. Lightweight structures rely for their behaviour on the performance of their connections and details. This is why the best, strongest, most durable materials should be used. Stress and deformations are focused in these areas, thus their design cannot be carried out approximately on site, especially in the event of an emergency, when lack of time could lead to mistakes.

MOUNTING AND DISMANTLING CYCLES

Joints and connections are affected by several external agents: they become weather-beaten; they undergo several cycles of setting-up/dismantling; they may suffer from long periods of storage where moisture or constant pressure can affect individual elements. Stainless steel elements are the most suitable solution due to the resistance of this material to external agents. The price has become, most of the time, prohibitive, therefore selection of alternatives must be carefully evaluated, according to each situation.

Durability of the elements has to be carefully predicted according to the intended lifespan of the product considered as a whole. All components and materials should be designed accordingly to avoid or, at least, to envisage the replacement of parts at defined stage of the sheltering process. This topic will be presented in Chapter 7.

2.5.2. Control of internal comfort

ALTERNATIVES TO MASS

To ensure thermal and acoustic insulation, mass is necessary. Conversely, lightweight constructions are systems where, by definition, the use of materials is minimized. In relation to thermal comfort, a smart design should take into account natural systems to cool shelters or keep them warm (e.g. natural ventilation or protection from moisture). A combination of different layers is the easiest way to improve thermal comfort. Sun shading devices together with waterproof layers are required.

[1] For temporary building and tents, operators of the sectors usually refers to EN 13782:2005

A combination of lightweight materials with massive systems is also possible. Local materials such as water, leaves or earth may also be considered and used.

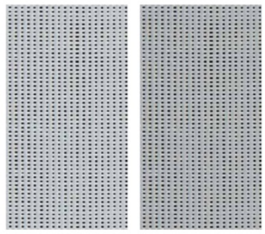


FIG. 2.8: PES/PVC MESH WITH LOW EMISSION TOP COATING

As for thermal insulation, a series of studies on winterized tents is available in the literature[2]. Specific coatings are currently available on the market which ensure low emissivity of materials when heated. The results seems promising even if the comfort is largely influenced by the correct application of natural ventilation, therefore every design must take air flow into consideration.

PRIVACY ISSUES

Meanwhile, a good sound insulation system for lightweight structures is still an issue and has not yet been studied in depth. Sound insulation can be crucial for refuges to feel safe and "at home" during the displacement period. Fabric finishing materials have low performance in terms of airborne sound insulation. A better performance can be obtained by the application of non-woven mattresses in combination with aluminium or lead sheets. This results in flexible but heavier and thicker finishing materials removing part of the advantages of these solutions.

2.5.3. Design and shape problems

PREFABRICATION

The design of lightweight construction is crucial for the success of the structure itself. Structures are mainly pre-fabricated and then assembled on site. Thus, not many changes can be made in the setting-up phase and this is the reason why everything should be carefully checked before being transported on site.

Knowhow about the structural behaviour of lightweight structures is technical and is not widespread among architects and engineers. Specific software is required for form finding and structure analysis. Improvising is definitely to be avoided, especially in the emergency field.

Some design and structural systems present restrictions in shape too. For example, sometimes, the dimensions of the structure are linked and related to one another (e.g. arcade construction where height and span are related according to structural behaviour).

Another example is behaviour under wind load: since different shapes react differently, and some configurations cannot be applied in windy areas.

Tie-back cables can be an issue too: they cannot be avoided and sometimes they produce restrictions in the usability of the structure itself. Safety problems can arise from them since they are outside the perimeter of the structure itself and are, in some cases, not visible at first sight.

All these aspects will be taken into consideration in the second part of this dissertation.

[2] Spence R., Manfield P., Corsellis T., (2000), *Cold climate emergency shelter system, a research project for humanitarian organizations*, Cambridge University.

2.5.4. Social acceptance

Social acceptance is the most complex issue concerning lightweight constructions. If technical problems can be solved within a well defined period of time (even if, in some cases, solutions are not sustainable), social acceptance requires time and effort and, sometimes, cannot be solved at all.

Social acceptance is not only related to beneficiaries but passes through the sector operator too. As highlighted in Chapter 1, the introduction of innovative technologies, typologies and materials is often risky and therefore their application may take much more time than it should.

As for beneficiaries, ethical issues may arise when a so-called "developed country" offers a "ready-to-use" technical solution to a "third world country", for example.

MAINTENANCE AND DEVELOPMENT

How should NGOs deal with the consequence of the application of alien technologies in local environments? Setting-up and maintenance phases are both crucial in this respect. The material used plays a key role in the success of the solution: familiar material can be substituted, repaired and reused locally also when the emergency has passed. Conversely, alien material needs to be repaired or maintained by external contractors who should be dealing with the emergency phase only. The rapid achievement of a self-sustainable condition for a population affected by an emergency is a major goal of humanitarian relief.

Steel and aluminium materials are perfect examples and lightweight constructions are the perfect application where social acceptance is concerned. Special structures, even if made as simple as possible, require components with a certain degree of precision.

Conversely, if masts (for the structures) or foundation systems can be built locally, it can be difficult to find alternatives to hinges, turnbuckles, tie-back systems, iron cables, stakes or eyelets; materials should mainly be made of metal, however, the majority of these items are so simple that they can be found almost anywhere where hardware shops exist. It goes without saying that the quality and durability need to be carefully checked.

2.6. The right process and the right sheltering product

The perfect shelter does not exist but better solutions compared to current ones can certainly be identified. A combination of different factors with vernacular architecture is the ultimate goal with a close look at the balance between the rapidity of the solutions and its integration with the local context, as learnt from acceptance issues.

Anyway, products are only a small part of the whole story: effective results may be achieved through a continuous process of implementation in later stages of the emergency according to the availability of resources and the evolution of the situation itself. Therefore, solutions deployed in the first days should be designed in a way that allows further implementation and upgrades.

ANALYSIS THROUGH CONTRASTS

In the following chapters the world of sheltering will be presented trying to combine the best of different methodologies and features which are presented in contrast. Starting from the assumption that any solution might have an audience and answer specific demands perfectly, but knowing in advance that the deployment of the right shelter in the right moment for the specific goal is an issue, Chapters 3 to 7 aim to offer a synthesis of current practice from a critical point of view and to support the choice that will take shape and action in the second part.

Contrasts are sometimes exaggerated to offer opposing views and give input to the audience who could be inspired to learn from different fields and experiences.

3 LIGHTNESS & SIMPLICITY

Lightness and simplicity are two pillars on which emergency response should be based. Lightness is, in particular, related to materials and their mass which is intended to be the minimal amount possible. On the other hand, simplicity is related to the combination of those materials, the way they are arranged to react to external loads and the system of assembling parts too. An optimum configuration is, most of the time, the minimal one, and takes advantage of material properties, using them at their limits. "Less is more" becomes the triumph of simplicity intended as the smart combination of those essential elements without any compromise in terms of performances, nay, improving them. Structural optimization is, for example, one way to combine lightness and simplicity towards the ultimate goal of an efficient structural system at minimal cost.

Fig. 3.1: Hanging camping

A straightforward application of these two principles in an emergency requires extensive knowledge from the material, structural, and physical building points of view, In addition, understanding of manufacturing processes needs to be taken into account too. The following paragraphs will highlight how lightness and simplicity are part of true lightweight architecture even if, sometimes, those pillars are only named for advertisements while the facts show the contrary. This excursus will have a closer view of emergency but not only: sport, a sector where performances matters, offers the most advanced solutions and researches in this respect. Leisure and art, on the other hand, make use of these principles to astonish people and make them aware that simple can mean beautiful. Application of these extremes in the emergency sector can be tricky: together with the high-tech/low-tech dualism presented in Chapter 6, this chapter seeks to prove that simplicity could vehicle the principle of lightness from high- to low-tech. In the case of application in the humanitarian sector, this idea will be quantified to better understand what the real impact of applying these principles in practical cases is.

Contamination from other sectors

3.1. Why lightness?

Lightness is not a technical term and cannot be measured in a finite way. It can be neither quantified nor specified but is a qualitative ingredient of modern architecture that is gaining momentum.

Chris Wilkinson[1]

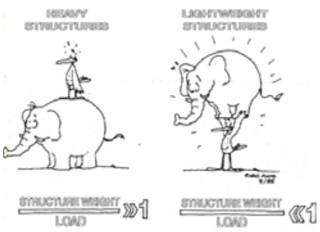


FIG. 3.2: HEAVY STRUCTURES VS LIGHTWEIGHT ONES

The definition of lightweight structures can be wide. "Lightweight" implies a comparison between different things: one thing is heavier than another one *ergo,* the latter is lightweight. It is clear that this definition is insufficient.

In architecture, this definition has to be better addressed: any structures that can carry much more load than the weight of the structure itself are generally considered "lightweight". This is in contrast with traditional structures (such as bricks, concrete or steel structures) in which the load-bearing capacity is the same or even less than the weight of the supporting structure.

Lightweight structures are special. Their components (e.g. membranes, struts, poles, cables, turnbuckles etc.) are visible both from outside and inside in a composition that is defined by their function: namely, the transmission of forces. This is in direct contrast to "ordinary" structures where structural components are usually hidden behind finishing elements and whose textures and forms are considered more comforting to human eyes and tactile senses. Although light structures may be painted, galvanized or plated, the structure itself, being clearly visible, becomes the architecture of both form and space.

STABILITY PRINCIPLES

Tensile structures, in particular, unquestionably represent a challenge for structural engineers. In fact, the stability of conventional buildings made of concrete, steel, wood or masonry is based on two main structural properties: gravity and rigidity. These properties make them stable and capable of transmitting load.

If masonry walls stay in place because of their bulky weight, steel frames carry load thanks to their rigid strength and resistance to bending. In tensile structures gravity and rigidity are not an option. Fabric structures, in particular, are so light that their weight is almost negligible compared to loads they can carry. Moreover, the materials of which they are made, such as fabric and cables, are highly flexible therefore, no bending stiffness.

FIG. 3.3: SUSPENDED STONES, KEN UNSWORTH

Other means need to be harnessed, therefore, to give stability and strength to a structural system consisting of textiles. Their components require arrangement in a specific geometric form (surface shape), while being subjected to a specific pattern of internal stresses (pre-stressed pattern). The geometry of a tensile structure is, therefore, not

[1] Brookes A. J., Poole D., (eds), (2004) *Innovation in Architecture*, Spon Press, London, New York.

arbitrary, but follows strict engineering rules[2]. This brings restriction in shapes but astonishing configuration have been investigated by architects, engineers and artists too.

3.2. Lightweight structures

Lightweight structures are more than just light materials[3]. The essence of engineering lightweight structures is a careful design of the force flow within the structure so that the minimal material required for a specific task is used.

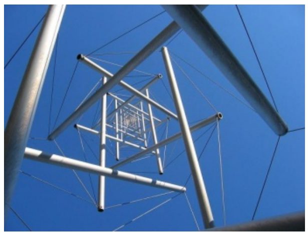


FIG. 3.4: NEEDLE TOWER, KENNETH SNELSON

From a structural point of view, cables under tension are extremely efficient, since the cable strength is independent of the length of the cable and is solely given by the material strength. However, whenever there is tension, there is compression too. And where there is compression length matters. The risk of buckling demands larger cross sections and, thus, more material. As a result, columns are heavier and thicker than cables as is obvious in the case of suspension bridges.

TENSEGRITY STRUCTURES

Constructive separation of tension and compression is a major goal of good lightweight engineering. The principle is fully adapted in tensegrity structures[4]-[5]. Astonishing sculptures have been built according to the tensegrity principle of discontinuous compression and continuous tension, however structures based solely on this principle are not common in architectural applications.

FIG. 3.5: KURILPA PEDESTRIAN BRIDGE, BRISBANE

The reason for this derives from the fact that these systems are a perfect example in which lightness prevails over simplicity. It has been proven that roofs and towers can be build with tensegrity but a lot of work has still to be done to turn a fascinating structural concept into an applicable building construction method[6].

This path has been undertaken by the development of Tensairity® principle which simplifies the separation between tension and compression thanks to the use of air, as will be shown later and, extensively, in the second part.

3.2.1. Ultra-lightweight constructions

Starting from all of these considerations and background, ultra-lightweight constructions represent a further step. Considering the previous analysis and looking at the limitation of tensegrity, ultra-lightweight constructions in this dissertation are defined as

---

[2] Berger H., (1996), *Light Structures - Structures of Light: The Art and Engineering of Tensile Architecture*, Birkhauser Verlag, Base.

[3] Luchsinger R. H. et al., (2004), *The new structural concept Tensairity: Basic Principles*, in Progress in Structural Engineering, Mechanics and Computation, ed A. Zingoni, A.A. Balkema Publishers, London.

[4] Fuller R. B., (1975), *Synergetics: Explorations in the Geometry of Thinking*, , MacMillan Publishing Co., Inc., NewYork.

[5] Pugh A., (1976), *An introduction to tensegrity*, University of California Press, Berkely.

[6] Maffei R. (2009), *Innovative lightweight construction: water and membrane*, Master thesis, Politecnico di Milano.

structures where the materials, design, layout and arrangement of the elements collaborate to bring lightness: the equilibrium of forces is optimized and materials must be carefully chosen and dimensioned.

Moreover, this author calls ultra-lightweight constructions those systems that perfectly match both lightness and simple features, without any compromises.

THE ESSENCE OF LIGHTNESS

The history of lightweight construction is full of controversial structures: some of these have been lightweight from a material point of view but have required huge anchor systems to withstand wind loads: as result, the temporality concept is not met due to the fixed foundations. Some others are incredibly light but, from a flexibility point of view, require additional structures/elements which ultimately double the total mass.

As for transportability, some inflatable domes can be lighter in terms of kg/m^2 than any other arch-supported tents available but, since the whole dome is a single element, transportation can require special machines and equipment.

DIFFERENT "WEIGHTS"

Set-up systems must also be considered in defining the "total weight" of the structure. Moreover, the sustainability of the solution provided, in terms of performance, reusability, but also energy consumption "weighs" a lot. Therefore, this author defines "ultra-lightweight" those constructions which can be can be considered light not just because of their mass, but mainly because of their design, taking into consideration the whole process from manufacturing to installation and dismantling.

FIG. 3.6: FUJI PAVILION, 1970

One of the most famous examples of a "tricky" lightweight structure is the Fuji pavilion built in 1970 during the Osaka Expo in Japan. It was based on 16 arch-shaped tubes of 4m diameter and 72m in length. Each tube was 4 tons in weight and the inflation and setting time was 5 days per tube. Total set-up time took five months and the total weight was 65 tons (about $35kg/m^2$). To make a comparison, modern air halls easily weigh $2kg/m^2$ and the setting up of a structure of a comparable size to the Fuji pavilions now takes only one or two days.

FIG. 3.7: PLUSMINUS – PNEUMATIC GRIDSHELL BY FESTO AND LTA STUDIO

A different approach was pursued at Bionic Learning Network of Festo[7] together with Studio LTA and ILEK[8] for the design of a grid shell based on inflatable tubes called PlusMinus. The prototype carefully balanced the overpressure inside the tubes and the vacuum created between two layers of transparent foils which entrap the grid. This combination assures stability with the minimum use of material thanks to the smart use of gradient of pressures.

FIG. 3.8: TUNNEL GREENHOUSES FOR AGRICULTURE

It is obvious that the load resistance and dimensions of the two projects cannot be compared but it is clear how quickly technology has evolved in less than 50 years.

From a simplicity point of view, PlusMinus is a further step and, from the lightness perspective, ten times lower. With its 3.78kg/m2 it can be a competitor for sports air halls which, being a single layer only, can rarely be surpassed by any other structural system. Meanwhile, the flexibility in its shape and the possibility to create enclosed spaces without the obstacle of doors to keep the ambient pressurized is a huge advantage.

[7] www.festo.com

[8] Institut für Leichtbau Entwerfen und Konstruiere, Universität Stuttgart www.uni-stuttgart.de/ilek

To find even lighter structures, one needs to look to other fields such as agriculture. Probably the most common widespread ultra-lightweight structure is the tunnel greenhouse, named caterpillar tunnel, in use extensively everywhere in the world.

The structural system is based on metal arches made out of hollow tube profiles bent on site according to the required dimensions and then hammered into the ground. Arches are connected by only one rope at their peaks acting as a ridge cable and then connected to the ground with a T-stake sunk. The cladding system is a simple thin polyethylene foil which is spread over the arches and fixed only at the beginning and end of the tunnel.

FIG. 3.9: EXTRA ROPES TO TENSION THE FOIL OF CATERPILLAR TUNNEL

To improve stability, extra ropes can be placed on top of the foil, between the arches and tied down. This construction system is extremely efficient, lightweight, can withstand a considerable amount of wind load and, the most important thing, can be built by anybody in the field adapting it to their special case. The expertise and tools required are minimal while the time depends on experience.

FIG. 3.10: MIDDLE EAST VERNACULAR CONSTRUCTION

It is interesting to note that this structural principle is in use by several north Africans and middle eastern people.

3.3. Weight vs. lightness

To have a clearer idea of lightness, we need to bear in mind certain figures and data on the weight of architectural elements or materials and investigate examples where weight is crucial.

In the event of an emergency, weight is a key issue for two reasons. First of all, transportation is easier when weight is reduced and this is true at any level, from the container to the bag. Secondly, if any component is lightweight, construction phases are dramatically speeded up and the risk of injures during construction is limited. These are the reasons why solutions are usually sorted according to available transportation systems or the workforce available for setting-up (number of men, machines etc.).

The following overview reviews twelve out of the many examples of sheltering systems used in humanitarian relief to try to give a general idea of the target of the products applied in an emergency.

The weight/square meters covered ratio cannot be taken as the only reference. Even if the solutions selected are comparable, every product differs in term of cost, wind load resistance, thermal comfort and durability.

An extensive and all.-inclusive test campaign would be required to come up with a reliable comparison to identify the best trade-off out of these options by matching all these variables. At the moment, we will focus only on dimensions and weight.

FIG. 3.11: ASSEMBLING PHASES OF FAST SET UP 6X6

The list of examples is arranged in rows: the first row shows solutions which are applied in “third world countries” by international NGOs; the second row presents examples of products which are used by local authorities in Italy, taken as an example of the “first world" area; in the third row, larger structures used as infrastructures or warehouses are presented.

Looking at those data it is clear that once we talk about humanitarian products, one needs to be aware of the variety of choice. Even if they are all defined "lightweight construction", among products to shelter people (families of groups) the range varies from 2.7kg/m^2 to 7.1kg/m^2.

Solutions for third world countries (first row) are much lighter, while the Italian *Protezione Civile* (Civil Defence) makes use of heavier solutions that should ensure higher performance (second row). The reason is clear. The first solutions have to be shipped all over the world by cargo vessels but sometimes also by planes. The second solutions serve a local area.

Fig. 3.12: Fast set up 6x6
W/l/h: 5,9/5,9/28 m
Area:34,6 m2
Weight: 327 kg
Kg/m^2= 9.4

Lightweight emergency tunnel

W/l/h: 3/5,5/2,1 m
Area: 15.18m^2
Weight:42kg
Kg/m^2= 2.7

Family tent - center pole tent

W/l/h: 4/4/2.75m
Area: 16m^2
Weight: 115kg
Kg/m^2=7.1

IFRC - Family tent

W/l/h: 4/6.6/2.2m
Area: 23m^2
Weight: 55kg
Kg/m^2= 2.3

Ridge type tent

W/l/h: 4/4/2m
Area: 16m^2
Weight: 85kg
Kg/m^2=5.3

Family tent

W/l/h: 5.5/3.1/2m
Area: 17m^2
Weight: 55kg
Kg/m^2= 3.2

Montana 19fr

W/l/h: 5.1/3-9/2.65m
Area: 19.8m^2
Weight: 101kg
Kg/m^2= 5.1

Montana Pneu tex fr 4 arches

W/l/h: 5.6/6/2.85m
Area: 336m^2
Weight: 185kg
Kg/m^2= 5.5

Rapid Rescue

W/l/h: 5.6/6.4/2.8m
Area: 36m^2
Weight: 108kg +23kg
Kg/m^2= 3.6

Multi-purpose tent

W/l/h: 5.8/7.5/2.9 m
Area: 44.5m^2
Weight: 194kg
Kg/m^2= 4.3

Multipurpose Giertsen Hall NG15

W/l/h: 6/8/3m
Area: 48m^2
Weight: 200kg
Kg/m^2= 4.1

warehouse Wiik hall EX 10x24

W/l/h: 10/24/3.35m
Area: 240m^2
Weight: 2371kg
Kg/m^2= 9.8

Fast set up 6x6

W/l/h: 8.25/12.7/4.1 m
Area:105m^2
Weight: 566kg
Kg/m^2= 5.4

Fig. 12-23: weight per M^2 of most common types of sheltering

Both products are prepositioned, the first are stocked in large warehouses all over the world and close to “hotspots” like Indonesia, Dubai and Panama; the second are stockpiled in accessible regions in the centre of Italy. The first solution has to reach even remote areas while the second are usually set up in planned locations (camps) which are identified in advance and easily reachable in any case.

If in the first cases shipment and logistics is crucial, in the second, the comfort and ease of set-up (camps are built by practitioners while family tents in third world countries are, in some cases, even distributed directly to locals) are the main priorities.

In the case of products dedicated to assets or infrastructures such as hospitals, logistics or working areas, numbers vary according to the load bearing capacity and the ease of set-up.

“Fast set up”

One model called “Fast set up 6x6” deserves to be looked at in more detail. Its structure is a foldable aluminium frame with shock-corded poles. Set-up is fast (four people in three minutes) and wind resistance much higher than competitors, but it weighs double compared to other similar solutions (e.g. Montana Pneu). Its total weight reaches 327kg.

It is clear how lightness is, therefore, relative: 9.4kg/m^2 is an exception among family shelters while it looks more comparable to much larger structures (for example warehouses).

Foldable systems

Occasionally, weight can be counterbalanced by special features that make the solutions better for a specific application. This usually happens in the case of expandable and foldable solutions: it may be that “foldable” versions of a shelter are heavier compared to a standard, non-foldable solution. In these cases, the increase in weight is offset by ease of transport and speed of assembly. However, in most cases, foldable structures do offer a strong contribution in reduction of weight and these are the cases in which simplicity plays the key role.

3.4. The influence of simplicity

Bubbles are the most simple self-equilibrated structures and people have known of their properties since ancient times. On the other hand, reproducing the beauty and simplicity of bubbles is not as simple as it looks. The example of the studies carried out at ILEK by Lucio Blandini on a glass dome are proof of how difficult it is to pursue simplicity. Blandini came up with a frameless glass shell which is fully optimized and uses the latest development in materials such as 10mm curved and chemically reinforced glass panels glued together for the shell, and titanium for the frame construction which aimed to simplified and develop the construction of the glass dome which often requires a large amount of steelwork.

Fig. 3.25-26: Frameless glass shell, Lucio Blandini

As shown by this example, simplicity has a meaning in relation to the application of it in a specific case. The response to the optimization of building a transparent roof has generated demand for the development of simpler construction methods. In an emergency, simplicity influences several different factors. Portability, flexibility, the concept of the minimum and sustainability are just some of those which also are closely related to lightness and will be presented later on in this chapter.

3.4.1. Simplicity and portability

Portable architecture consists of structures that are intended for easy set-up on a site remote from where they have been manufactured. People in charge of the assembly phase, have relatively little experience in construction: they can be either practitioners or victims themselves. Ease of assembly is generally related to the level of portability of the solution. Three different levels of portability linked to specific levels of transport can be identified:

LEVELS OF PORTABILITY & MEANS OF TRANSPORT

1) full volume systems, mainly at container level;
2) component systems, mainly at the level of bags and, sometimes pallets.
3) compactable systems, mainly at the level of pallets;

FULL VOLUME SYSTEMS

The full volume strategy is the simplest portable method and consist of buildings that are transported in one piece, fully equipped, and already assembled for instant use once they arrive at their location. Some incorporate their transportation method into their permanent structure and may be built on a chassis or a hull. Such buildings are generally restricted in size due to transport limitations (standard container sizes (ISO) are two: 244 (h)*259 (w)*610 (l) or 244(h)*259 (w)*1220 (l)). In this case, the volume transported is the same as the volume in use, moreover, the transportation means (the container) is the structural building component itself.

FIG. 3.27: CONTAINER HOUSES AFTER THE UMBRIA EARTHQUAKE, 1997, ITALY

These solutions are mainly dedicated to events and leisure activities and are installed by specialists. Application in emergency are dedicated to hospital posts or operating theatres. In the Western world, container houses have been largely used to address the needs of victims who have lost their homes, especially in cold areas, during wintertime (in the Italian case, this solution was applied after the earthquake in Irpinia 1980, in Umbria 1997, and for the winter of 2012 in Emilia).

FIG. 3.28: OPERA TRAILER

COMPONENT SYSTEMS

Extra expandable devices such as concertina walls or moveable parts can be incorporated to enlarge the volume once on site. The advantages of these solutions come from the incredibly short set-up time and the integration of furniture and sanitary systems. Transportation, on the contrary, can take more time compared to other strategies and can sometimes generate its own problems, for example, if the structures have to be provided for remote sites. Caravans are examples of this category too.

The opposite method, which enables a larger variety of forms, is based on an assembling/disassembling approach to components. In this case, the building is constructed from factory-made elements transported as single elements and then quickly assembled on site. These buildings can be packed and stored in a small volume: in this case, the volume transported is several times less than the volume of the shelter in use. According to the number of elements necessary, the shelter can improve upon and/or enlarge its final configuration. This strategy needs a workforce on site to assemble the component into the final shelter.

FIG. 3.29: ASSEMBLING OF INFLATABLE TENTS: PROTEZIONE CIVILE'S TRAINING

The advantages of this solution come from the optimization of the shipping methods and the possibility to access any site; the drawbacks derive from the time wasted on the construction site and the level of knowhow required for the assembly phase. The shorter and easier the set-up is, the more effective this solution will be. Elements are usually simple and standardized thus expansions or additions are possible and fast. Standard tents but also recovery kits are well-known solutions in this category.

FIG. 3.30: ASSEMBLING OF A WAREHOUSE: RED CROSS TRAINING

A third type of portable building lies somewhere in between the first two options and is based on a fully integrated but compactable system, easy to transport and usually deployed or dry-assembled on site. This option offers a larger variety in shape and typology compared to containers and tries to minimize the drawbacks of the previous solutions while combining the advantages of both. The volume to be transported is lower compared to container systems but higher than having all components divided.

In this case, the assembly method has to be studied accordingly to be simpler and faster compared to the component solution, and while personalization is possible, it is rather limited.

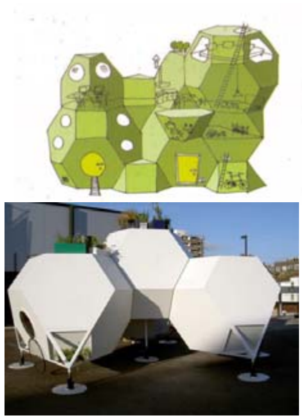


FIG. 3.31-32: "MICRO DWELLINGS" PROTOTYPE BY N55, 2005

This was the concept behind the visionary "Micro dwellings" by N55 (2005). This is a system for making low-cost dwellings of variable sizes for any number of persons consisting of movable housing modules that can form different configurations on land, water and underwater. Micro-dwellings are modular which allows them to be stacked up, rearranged, or clustered together with other systems to form small communities. In an emergency, some transitional shelters, but also some prefabricated modules are examples of this category. *Exo shelter unit* by "Reaction housing" divides the provision the shell and the floor optimizing the shipment of the components which can rapidly be assembled on site.

To sum up; both containers and compactable systems are fast to set up but personalization and implementation over time are usually tricky or, sometimes, impossible. Conversely, when the product is disassembled, especially in the case of kits, the result is much more "open" and allows different arrangements according to different applications.

The former are "ready-to-use" solutions: the definition of the foundations and the deployment are the only actions required on site; the latter need more time and effort in the construction phase but are much easier to transport. A comparison between emergency solutions out of these categories, not only form the portability point of view, will be presented in Chapter 5.

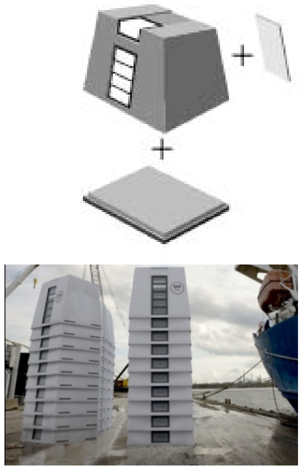


FIG. 3.33-34: EXO SHELTER UNITS BY "REACTION HOUSING"

3.4.2. Simplicity and flexibility

"Flexible architecture responds to today's living problems and predicts the architecture of tomorrow. Flexible buildings are intended to respond to changing situations in their use, operation or location. This kind of architecture adapts rather than stagnates, transforms rather than restricts; it is motive rather than static, interacts with users rather than inhibits. Flexible architecture is not a new phenomenon but a form of building that has evolved while human beings were developing their creative skills. Most people are used to architecture that is essentially composed of static solid objects, but the possibilities of completely flexible buildings are limitless. Extreme possibilities consist in a house that is designed for one person during the week and changes into a six-person house for the weekend to host relatives and friends. Or a home that can be folded and taken with you on your business trip. Or a building that fits your individual needs now but that you can invest in over the course of your life and divide up between your children to give them each a starter home when they need it"[1].

FIG. 3.35-36-37: "MARKIES" BY EDUARD BOEHTLINGK

These concepts are not typical of our age, especially in Western counties, while they lay at the basis of the nomadic cultures of hundreds years ago. At any rate, new phenomena have lately arisen especially in relation to changing lifestyles in the areas of work, sports and leisure: techno-nomads[2], people demanding high flexibility due to their continuous changing of habits, needs and position.

Consequently, flexibility is not only related to volume but mainly to performance, and it acts in time. What makes a building successful is the number of possible transformations over time and its adaptation to external environmental and boundary conditions but also users' demands. Changing climatic conditions or lifestyles, for example, require adaptation over time and this is why flexible architecture needs to be able to modify its components as quickly and easily as possible. Flexibility over time in the world of emergency architecture will be more deeply investigated in Chapter 7 while examples of products of architecture which adapt their layout are mentioned here. These structures can be grouped into two categories according to the level of flexibility they offer.

Modern camper trailers, for example use a number of devices to expand the room available once they have arrived at a location, such as a rising roof or pop-up rooms. The simplest system is a roll-up awning that can be extended from the side of the trailer to cover a space that forms an external living room. Dutch architect Eduard Boehtlingk's "Markies"

[1] Kronenburg R., (2007), *Flexible : architecture that responds to change*, Laurence King Publishing, London.

[2] This definition is the result of the studies of Thomas Baurley in the early 1980s identified a specific category of people with a lifestyle based on travelling for leisure or work purposes.

camper trailer uses this strategy: once you arrive in place the walls fold down and become floors while the new space is enclosed by a concertina-like membrane. Hundred of devices are available and flexibility is limited and related to one or two deployments of part of the original configuration through simple movements like rotation or sliding.

Based on the same principles the "GucklHupf" uses sliding, opening and rotating panels to allow a range of shapes and views starting from a prismatic form signifying the tension between "strange and familiar, quiet and movements, living and travelling"[3].

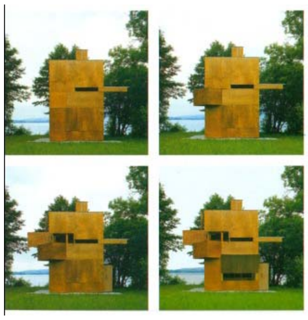


FIG. 3.38: "GLUCKHUPF"

Meanwhile, there are visionary projects which try to go beyond the old vision of flexibility as the adaptability of several layouts, pushing the development of the whole architecture which becomes able to modify its configuration by reacting to external agents. This is done in "muscle" through a series of actuators (the muscles) that modify the shape and the volume of the pavilion which becomes "alive".

FIG. 3.39: MUSCLE BY ONL 2003

3.4.3. Simplicity and the concept of minimum

Minimum means optimum, light and efficient. The concept of "minimum" lies at the basis of any lightweight membrane construction and it is the secret of its simplicity.

In mathematics minimal surfaces have meant a curvature equal to zero: these surfaces have the interesting properties of minimizing their area subject to constraints. Physical experiments with minimal surfaces can be easily carried out by dipping a wire frame into soap solution. The resulting surface is the minimal one which can connect the borders.

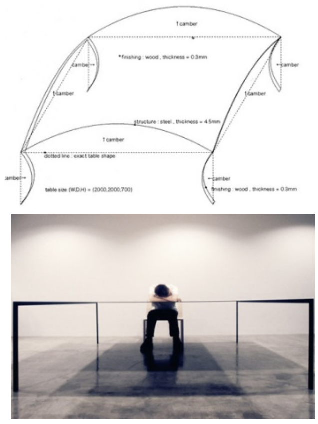


FIG. 3.40-41: MAGIC TABLE, JUNYA ISHIGAMI, EXHIBITION, TOKYO 2005

Minimal structures are not only ones that use the minimum amount of material. From a design point of view, the concept of minimum plays a key role in the definition of the shape and forces within a lightweight construction.

Given that the form of lightweight structures derives from the forces that are acting within the structure itself, by controlling these forces, it is possible to control the shape of the whole structure and to optimize the final design.

Tensile structures find their minimal form by reacting to the forces applied to them. They find an equilibrated form under a given loading, where there is only tension in the membrane. Moreover, by minimizing the forces, sections of materials can be reduced. This is why, by applying specific loads and restrictions, the behaviour of the whole structure can be improved and therefore, minimized.

FIG. 3.42: RAKOWITZ, PARASITE MINIMAL HABITAT 2007

And minimum is strictly related to natural. Minimal surfaces, volumes and distances are present in nature too. Bubbles or drops of liquids are just two examples of well-known equilibrium phenomena. Learning from nature is a topic which has been extensively investigated in contemporary architecture[4].

In parallel, minimalism has also become popular both in architecture and design.

The climax that has been reached in minimalism is clearly shown in the works of Junya Ishigami with his artwork which consists of a steel table, 9.5m long, 2.6 m wide, made of a

FIG. 3.43: LUCY ORTA, REFUGEE WEAR, MINIMAL SHELTER, 1996

[3] Richardson P., Dietrich L, Ed. (2001) *XS: big ideas, small buildings*, Thames & Hudson, London.

[4] Portoghesi P., (1999), *Natura e architettura*, Skira, Milano

single pre-stressed 3mm thick steel plate, which rested just on four legs at its corners. The table stays in its perfectly flat position thanks to the weight and the position of the elements which lean on it while without an object it would be bent.

In the field of architecture, minimal is related to minimal space (or volume) which is directly related to minimal standards that derives for human measures. Beds, tables and furniture in general are designed following minimal standards.

In an emergency several guidelines set minimal standards while artists foresee minimal survival dwellings that make use of urban services, for example, the heating systems of office buildings as foreseen by Rakowitz.

Minimal shelters to survive in polar regions or high mountains are presented by Orta as an optimal combination between a dwelling and a coat which allow a view of the outside without opening the door, thereby keeping the heat inside.

3.4.4. Simplicity and sustainability

AMOUNT OF MATERIAL, ENERGY CONSUMPTION, REUSE AND RECYCLE

Sustainability is a complex topic. For this dissertation, sustainability is only described in relation to ideas of lightness and simplicity, focusing on three aspects: the amount of material used, the energy consumption of the structures and the reuse or recycling of the materials.

Sustainability is definitely related to the amount of material used for building a structure. “Less is more”, as mentioned previously, from the sustainability point of view, is fundamental. The less material used, the less energy is required, and the less pollution and less waste material is generated.

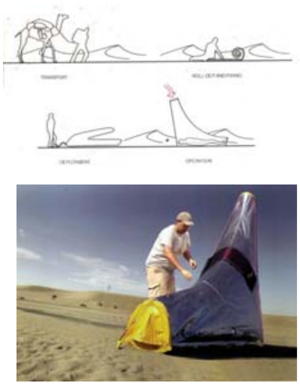


FIG. 3.44-45: DESERT SEAL CONCEPT AND PROTOTYPE, VOGLER (2004)

In the case of lightweight constructions the amount of material used is strictly that required to support the loading conditions, nothing more. Moreover, lightweight structures are designed to react to external forces in the most efficient way. Only tension and compression forces are present and bending moment or torque are mostly avoided. This is the reason why structural elements can be thin and slender.

From the energy consumption point of view, lightweight constructions cannot be compared to traditional structures. To provide indoor quality, mass matters. Thus, lightweight solutions and systems have to be applied in specific climate conditions. Well designed shading systems have to be taken into account and special attention should be given to natural ventilation.

A good example is the “Desert seal” by Andreas Vogler, an inflatable tent for extreme environments that makes use of temperature curves in hot arid regions where the air gets considerably cooler the more distant it is from the earth’s surface. This effect is used by many desert animals, not least the camel. This is why an electric fan constantly blows cooler air from the top of the tent into the body of the liveable space within. The tent consist of an “air beam” structure made of yellow polyurethane-coated polyethylene fibre and its awning is a silver coated high-strength textile that reflects heat and protects form direct sunshine. The beauty of this configuration derives from its functionality and efficiency.

From a material point of view, simplicity means designs which are dry-assembled and, therefore, can be easily dismantled. For this reason, components can be easily separated and materials sorted according to the recycling cycle or be re-used for new purposes. As an example, the reuse of different elements which are introduced in an emergency, for example, as packaging devices, can lead to suspended floors or to insulation of reinforcing materials for local constructions.

FIG. 3.46: REUSE OF CARDBOARD BOXES

3.5. Shelter performance

FIG. 3.47: HOT-AIR BALLOON, DEVELOPED FOR RED BULL STRATOS,

When a product needs to offer the highest performance, lightness and simplicity are two important features. These characteristics can enhance cutting edge innovations such as the astonishing hot-air balloons built in the last few years: starting from the reversed one developed by Festo or the 64m high one used to fly a man out of the atmosphere to beat several world records.

Lightness means a careful understanding of the essence of the task the element has to fulfil. Efficient designs last over time and are not subject to passing trends. They set a reference for other systems and even if technology evolves, they keep their value. A perfect example is the umbrella structure which remains one of the most efficient structures. Starting from this concept, Future systems have designed an umbrella-like structure for emergency application too by scaling up the load bearing structure which would be able to host a large number of people.

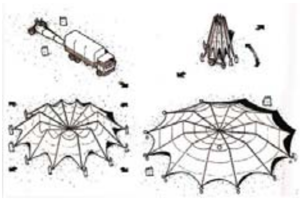


FIG. 3.48: UMBRELLA-LIKE STRUCTURE, FUTURE SYSTEM, 1989

Simplicity means finding and endorsing the specific performance of each material for its particular application. The correct application of each material in the right way often ends up in a dramatic simplification of the product itself with considerable advantages in terms of cost, usability, durability and performances in general. This process is often successful when materials are transferred from one sector to another.

This is the case of the glass fibre reinforced polymers which are a common material in the sailing industry while their application in architecture is still limited. The application of thin GFRP rods in camping tents is now common and thanks to the flexibility of the material, the well-known “2 second tent” by Quechua has broken into the market. In this design, as simple as it is smart, major advantages are achieved in terms of fast deployability together with an efficient and easy system of packaging.

FIG. 3.49: TWO SECOND TENT, QUECHUA

4 MODULARITY VS. ADAPTABILITY

In this dissertation, modularity has not been taken into consideration until now. This author thinks that a traditional modular approach may not solve the problems which characterize sheltering, and, in some cases, might strongly affect the development and reconstruction phases of a community which may not be able to return to its original condition on his own.

Even if in literature, modularity has always been identified as the fundamental principle on which every solution that aims to fulfil rapidity and efficiency should be based on, this author believes in the potential of much more effective alternatives: solutions which offer an implementable and flexible system in contrast with the rigidity and standardization offered by modular based concepts. As mentioned in Chapter 3, flexibility has to be pursued deeply while modularity would lead to static configurations which, at the end, are not flexible at all. Adaptability, on the contrary, is something completely different which can be achieved through several strategies. In particular, the world of lightweight structures can rely on adaptability due to the particular properties of the material involved and the specificity of the contest while alien architecture (containers, rapid deployable systems) has to rely on the modularity of the systems which need to modify, sometimes massively, the already vulnerable existing urban and even industrial contest.

Adaptable solutions are influenced by the context and they fit into it while modular systems interact and match each other perfectly but are rarely able to open themselves to the environment.

It is clear how advantages of modularity strongly affect the design and planning phases which can be easily arranged or modified according to spatial necessity: shipment, logistics and the training of volunteers can be adapted in a matter of hours. But it is in the phase of construction when modularity reveals its limits. On site, local resources and contingency may give precious inputs and may offer even better solutions to the community: therefore adaptability, in the sense of "open design" would allow more *freedom to set up the best configuration rapidly as soon as the boundary condition becomes clear or by adapting to them if anything changes.*

4.1. Modular approach

Modularity refers to the design of any system composed of independent and separate components that can be arranged together. The advantage of modular architectural systems in general is the possibility to replace or add any component (or module) without affecting the whole system. At the opposite of the modular approach, are integrated systems in which different functions are merged in a few components, strictly dependent on each other. If in the first case, the absence of one or more modules does not compromise the operability of the structure, in the second case, if one part fails or is not available, the system usually become weak or even useless.

MODULAR AND INTEGRATED APPROACH

Modularity set its basis in the design of the single module: a system which is modular can be shaped and adapted to different needs and requirements and its layout can be modified according to the arrangements of those basic elements but also according to the availability of resources, the number of people involved and the function of the structure.

From this point of view, the flexibility of modular designs is extensive and a great variety of configuration can be defined. This is how base camps are usually designed and planned according to the location, the number of people to be sheltered and so on. The design of modular architecture is therefore, based on strict rules which derive from the modules themselves.

Effective modules are flexible in arrangement and can be adapted easily to different contexts. In addition, the benefits of modularity rely on the development and application of compatible systems e.g. connections or joints which allow aggregation and extension of the basic module into an endless variation of shelters by integrating modules from other systems (e.g. integration of shelters with containers).

The limits of this approach arise in the case of rigidity: when these modules have a limited possibility of variation, modularity may hinder the intervention, offering solutions which do not match users' needs. Standardization becomes a limit and variation may be possible from a design point of view but becomes much slower on site.

"OPEN DESIGN" STRATEGY

At the opposite end, is the "open design" approach which focuses its attention on the construction phase: an open systems allows users, up to certain limits, to adapt and vary the configuration on site, at the moment of construction, taking advantage of the environmental conditions of the specific location. For this reason, every design is unique, and becomes time consuming: in the case of lack of time, modularity remains, therefore, more efficient while an adaptable open design gives more long term benefits.

4.1.1. Compatibility of modular systems

COMPATIBILITY

It is not the intention of this chapter, nor would I say, of the whole dissertation, to claim which approach is the most effective. As clearly stated in the introduction, there is not one answer. On the contrary, the aim of this part is to distinguish which characteristics are most promising and therefore, to identify the properties which, an innovative solution should focus on.

For this reason, modularity must be distinguished from compatibility: the former has been described extensively in the paragraphs above while the latter is the true essence of the success of an adaptable solution and will be investigated further below.

Modularity in itself, seen as a mere definition of measures, components and materials is a "top-down" solution. Unfortunately, as already mentioned, in the case of an emergency, the process of sheltering is mainly done progressively on site, following a "bottom-up process" able to take into consideration those boundary conditions which change continuously. This is why compatible and adaptable solutions are required, in contrast with modularity which is based on a standard design though far from the emergency.

This author believes that the best solutions are the most adaptable ones which are able to approach the problem from another point of view. Instead of offering alien solutions which do their job independent from the context where it fits, adaptable structures learn "on the way" and offer the best trade-off in terms of performance and stimulation of the local context/economy, allowing a progressive implementation of the systems towards the development and reconstruction phase. In this way, adaptable systems are able to bear in mind the bigger picture while offering solutions for contingencies. The trade-off is, of course, the speed of deployment. Planning based on standardized modules are the fastest, while adaptation to every specific case may cause delays; but will provide benefits in the long term.

FIG. 4.1: MSF, INFLATABLE HOSPITAL CAMP

Instant city of Ibiza is a perfect example of this issue. Born as an "alternative world" and built based on the inflatable technology which had a strong appeal at that time, it lives a paradox. The new city wanted to be flexible, adaptable and, based on modularity, sought to offer the dream of sheltering and to host endless numbers of people, thanks to continuous additions. On the contrary, the facts tell that limits in shape and layout were tremendously higher than any other short of construction and probably readers could find similarities with the standard arrangement of hospital camps both for military or emergency purposes.

FIG. 4.2: INSTANT CITY IBIZA 1972

This is the proof that flexibility of material does not always mean flexibility of layouts, nay, sometimes flexible materials are limited to strict and rigid modules where they lose their peculiar properties which are not exploited to the limit.

FIG. 4.3: AIRCLAD BY INFLATE

Airclad by Inflate is one example of this. The modular systems allow incremental extensions of the living cell but the resulting layout does not take advantage, for example, of the textile envelope around it and does not differ much from standard container-based solutions.

The main criticism of the wrong application of modular strategies in the case of an emergency is the fact that an innovative approach needs to go beyond the simple collocation of basic elements one close to another.

Modularity should not only be seen as a geometrical frame of rules which allows an easy and fast aggregation of simple modules. Following this theory, every module is designed to fulfil minimal standards and the right combination of some of them should automatically turn them into dwellings, hospitals or community centres. If this may be true for a very limited lifespan, it can also be totally wrong in developed countries where emergencies last for years and these solutions become permanent dwellings for the victims.

4.1.2. Different levels of modularity

Modular architecture is based on "bricks" which are arranged in a particular way to address specific needs. The success of the system strictly depends on the effectiveness of the selection of those basic elements. Modular systems can be sorted according to the characteristics of these sub-systems which can be divided into two large macro areas: modules or components.

Module based systems

In this case, every single module is designed as an independent, stand-alone subsystem. Modularity lies in the possibility to connect or pile several modules in a way that creates different geometric layouts. Aggregations of containers, tents or other "closed" subsystems are in this category.

The Advantages of these kinds of system are mainly related to geometric and spatial management such as the rapidity in adding new modules according to need and the simplicity in replacing or removing modules without affecting the whole system. Flexibility, as shown above, is pretty limited and mainly related to the geometric aspect of the architecture, therefore, this approach gives its best in the event of lack of time or when the duration of the emergency is limited.

FIG. 4.4: SPACE BOX, STUDENT HOUSES, UTRECHT, 2004

These systems are mainly "closed" and can rarely be implemented by users over time especially due to the fact that the technology involved is, in general, quite specific.

This kind of approach is often used to answer specific needs such as offering cheap, fast-to-build and relocatable student houses for Dutch universities, like the Space Boxes.

Component based systems

On the other hand, there are systems which are based on simple structural or cladding components, which have relatively low value if taken by themselves while, if connected, may greatly increase their potential.

FIG. 4.5: UMBRELLA HOUSE, KENGO KUMA, MILAN, 2008

This is the case of the Umbrella House by Kengo Kuma. The concept of this pavilion arose from the reuse of a standard umbrella in a modular way. The umbrellas are provided with zippers on the edges and extra flaps to allow a larger variety of configurations. With a minimum number of modules, a compete dome can be set up. By changing the number of umbrellas or the edges of some of them, different constructions can be made.

4.1.3. Modularity and logistics

Modularity gives of its best to solve logistical and packaging issues. Modularity is, therefore, based on the transportation means available. Containers and pallets are standardized and based on these measures, to which most of the shelters, either for emergency, military but also leisure, have been designed.

Fig. 4.6: Pallet house Azin Valy and Vini Suzan, 2008

At the level of the module, the packaging dimension needs to fit standardized sizes. Integration of modules with the means of transport is highest at the container level: the container is, at the same time, the structure and the packaging device.

At the pallet or bag level, everything changes: modules can be stockpiled in different ways but means of transport are rarely integrated into the structure of the final shelter.

A few exceptions can be found: at the pallet level, the "pallet house" reuses euro pallets as construction materials for walls, roofs and floors. At the bag level, transportation devices may be useful to complete the construction of the shelter but also to protect services such as the blowing system in the "office in a bucket" pavilion.

Fig. 4.7: Office in a bucket, inflate

4.2. Modularity and adaptability

Leisure pavilions, especially the ones which are rented periodically for events and parties, are based on modular systems. Modularity, in these cases, reveals its advantages in term of simplicity of assembly which is based on compatible and repetitive elements and connectors. Structural modularity can be pursued through linear, planar or spatial elements too.

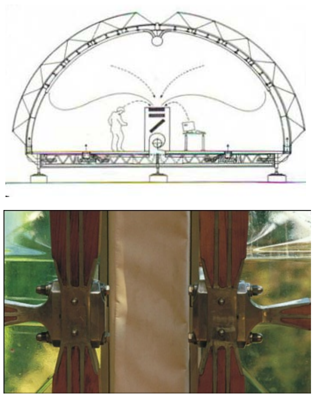


Fig. 4.8-9: IBM travelling pavilion by Renzo Piano

Renzo Piano's travelling pavilion for IBM is an example of an investigation into a modular arch-based structural component which is, at the same time, the structure and form of the pavilion itself. The beauty of this system lies in the details and in the cladding system, which collaborate in the stability of the structure and are designed to be modular and to interact with the different subsystems of the whole building.

Meanwhile, as shown in picture 4.7, the joints play a key role in the stability but also in the beauty of the construction itself.

As is clearly shown in this case, modularity does not mean standardization: the elements are unique and the system is highly flexible thanks to the possibility of extending the structure, as much as is needed. On the other hand, interaction or integration of subsystems which are not part of the original design is limited or impossible. Assembly is possible thanks to trained crew. But the IBM pavilion is a unicum.

Commercial structures are very different. These kinds of system are modular, and their joints, profiles and connections aim to be universal. The success of these kinds of structure is the load bearing system, with beams and columns which integrate keder profiles to easily slide into roof and walls and are assembled by bending resistant plates or joints for connection.

Fig. 4.10-11: Aluminium frame tent, typical connections

The profiles of joints and floor connections have been developed by companies specializing in the sector and are standardized. Except for minor changes, the systems follow all the same principles and allow integration with several different finishing materials, from a single or double layer textile fabric, , low emission canvas, rigid panels, insulated walls or glass panels which turn easily and in few hours a temporary shelter into a semi-permanent or even permanent building. Design plays the key role here and therefore, the results are no poorer than those of standard architecture.

Fig. 4.12: Custom made design made with modular system of aluminium frame tents

In the case of application in an emergency, the versatility of these kinds of system make them the most widespread all over the world, from Western countries to remote areas. Systems have been developed and simplified in the last few years to allow construction by volunteers or even end users with limited skills in construction.

4.3. Adaptability: a bottom-up strategy

Fig. 4.13: Y-BIO by Alik Shelest deployment configuration

Starting from the example of the aluminium frame shelters of the previous section, the evolution of such an efficient modular system in terms of adaptability can be foreseen looking at the examples developed by Archinoma which clearly show the potential of combining modularity with adaptability. The prototype of Y-BIO designed by Alik Shelest offers the freedom of aggregations at both levels of modularity described in paragraph 4.1.2.

At the level of the module–the tetrahedron–the system allows the construction of a large variety of shapes: two-storey pavilions but also horizontal open pavilions or frames which interact with the local environment and offer their services independently from the core of the structure are possible.

Fig. 4.14: 4 dimensional design applied to shelters, Caroline Henrotay

Looking at the level of the components, the linear elements and cladding systems are also modular. Profiles, connection plates and cladding materials are the components but none of these are essential: they can be substituted according to the availability of components at the moment of the intervention. Connections and joints between components are the most important part in this design. The success of the system as a whole depends on the simplicity, reliability and openness of these elements.

For an effective application in an emergency, modularity and adaptability need to merge. If, on the one hand, the modular approach offers speed in delivery and a short assembly time, on the other, an adaptable approach offers a wide range of possible configurations based on a given system. To discover the best trade-off between these features, while keeping the advantages of both is a challenge. The main risk is to come up with systems that are much more complex than they should be.

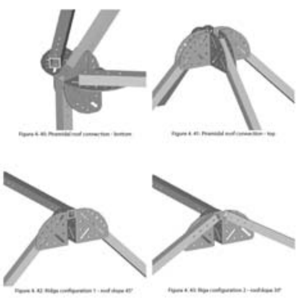


Fig. 4.15: flexible connections for the structure of a shelter, Caroline Henrotay

In trying to avoid the rigidity of standardized modular system, one should not end up in complex adaptable constructions which require supervision, time and effort to assemble and, therefore, are not reasonably applicable in an emergency. In addition, a large variety of possible configurations may also generate more confusion than benefits.

Focusing on a few optimized applications of the modular system, compatibility of components should be the key feature at the basis of the process to integrate modularity and adaptability. Compatible elements, connections and materials mean simple, adaptable solutions which are highly recommended in scenarios where certainties are rare.

The exhaustive research by Caroline Henrotay in this direction is brilliant. Her work is based on an investigation of the compatibility of structural components thanks to the definition and design of a series of optimized three dimensional connectors. Structural optimization in terms of lightness and adaptability[1] remain an open problem but again, it depends on requirements and, therefore, will not be the focus of this discussion.

4.4. Sheltering as an open design process

Based on this approach, an enormous range of possibilities can be explored: instead of designing the solution which is optimized for a specific condition, the sheltering process may be based on a series of modular and open components to let locals, victims and volunteers identify the optimal configuration to be set up, according to variables which arise on site at the moment of construction. Based on these tools, sheltering may take advantage from the input of the victims by sharing the same building technologies both for rapid deployable systems, in use from the very first days, and for dwellings meant to be transitional or even permanent.

COLLABORATION OF VICTIMS

Having the final users engaged in the process of reconstruction would stimulate a bottom-up participation towards development which has enormous advantages. First of all, the problem of requirements is partially reduced. This is not a shifting of blame from the practitioners to the victims however, the active role of the final users is a precious value, especially from the acceptance point of view. Secondly, victims would integrate the knowhow on the affected community that comes from mapping. Thirdly, local communities would be able to deal with the technology applied and, therefore, would be able to repair, implement and modify the new dwellings by themselves without the continuous help of external actors.

These approaches enhance ownership and responsibility and build up the basis for the future development of an area. To reach this goal, openness in design not only passes through modularity and adaptability: a more detailed analysis of ready to use systems (Chapter 5) and low- and high-tech sheltering systems (Chapter 6) must be taken into account.

---

[1] Debacker W, Henrotay C, De Wilde W.P and Hendrickx H, (2006) *Adaptable versus lightweight designs of transitory dwellings* Proc. of 1st Conf. on Ravage of the Planet, Management of Natural Resources, Sustainable Development and Ecological Hazards, eds. C.A. Brebbia, M.E. Conti, E.Tiezzi, 331-339 Wessex Institute of Technology UK

5 READY TO USE SYSTEMS: "ALL IN ONE" VS. "COMPONENT BASED" APPROACH

As shown in Chapter 2, every disaster must be addressed with a specific solution. In any case, during the first hours after an emergency has occurred, the needs are usually the same and this is why a humanitarian response looks for universal solutions which can be deployed rapidly in every situation. The main tasks of the rapid deployable shelter are two: to keep people dry and/or shade them from sun and to give them a sense of protection by offering a safe and clearly visible place where to rest and find help.

These needs can be addressed in several ways, but they can be grouped into two main strategies: "all in one" approaches and strategies based on components or "kits". The first option offers advantages when lack of time is crucial and setting up times need to be reduced as much as possible. The same systems are useful when meteorological conditions are prohibitive and construction would became a difficult task. Currently, solutions of these kinds are typically alien in relation to the environment and they are dismantled as soon as the emergency has passed to be reused in another location. "All in one" solutions are mainly set up by volunteers and are "closed systems": modifications and adaptation is limited or even not considered. This approach is typical of Western countries. The second option is mainly applied in third world countries and in goes in the direction of involving locals in the construction and setting the basis of improvement towards development. This approach aims to integrate the sheltering process with existing dwellings and aims to be the first step towards the development phase.

This chapter investigate the advantages of both solutions trying to come up with a synthesis of the main characteristics that an innovative shelter approach should present.

5.1. First and third world countries: two different cases

FIG. 5.1: IFRC SHELTER KIT

FIG. 5.2: APPLICATION OF PLASTIC SHEETING IN HAITI

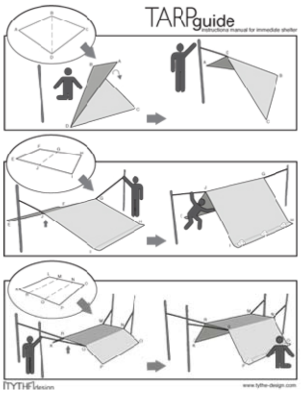


FIG. 5.3: TARP GUIDE, TYTHE DESIGN

Considering the fact that the provision of family shelters[1] may require some days, NGOs and local authorities usually rely on rapidly deployable solutions which offer, strategically, a kind of "buffer" period to complete the assessment and organize the process of sheltering in a better way. To address these needs there are two different approaches according to the area where the disaster happened: either Western or third world countries.

In the first scenario, all in one products are used. The best known examples of this category are inflatable systems which, due to their high costs, are only applied in the West where the deployment is organized in camps and setting up is demanded of practitioners. Rapidly deployable structures of this kind, currently in use by NGOs are of different nature and will be described in more detail in the next paragraphs.

In the case of use in third world countries, on the contrary, to address the needs of victims in the very first hours, the humanitarian sector usually relies on two different processes of sheltering.

The first case is the well known "plastic sheeting[2]"strategy, based on the massive distribution of simple "tarpaulin[3]" foils of 6m by 4m or a "shelter tool kit[4]" which combines two tarpaulins with a series of tools such as a hammer, saw and nails. This kit is meant to put people in the condition to self repair their dwelling (roof blown away, wall collapsed) and/or to set up a basic shelter which is able to protect them from sun and rain at least for the very first hours.

To came up with a stable safe shelter, using the components of the tool kit only, is not as easy as it seems. In the case of Haiti, 630,000 plastic sheets were distributed allowing people to protect themselves from the sun and rain. However, there was a risk that many of the spontaneous settlements would become the slums of the future[5]. Therefore, several guidelines[6][7][8] have been published to let people know how to manage the construction with such essential materials. The goal of these guidelines is to avoid the major problems and mistakes related to self-construction which range from the collapsing of the structures (which were not assembled or reinforced correctly), to the spread of diseases (e.g. malaria,

---

[1] UNOCHA, (2004), *Tents, A guide to the use and logistics of family tents in humanitarian relief*, UN publication

[2] IFRC, Oxfam, (2007 b), *Plastic sheeting, a guide to the specification and use of plastic sheeting in humanitarian relief*, Geneva.

[3] Tarpaulin is the name used by humanitarians to identify woven high-density polyethylene (HDPE) black fibres fabric laminated on both sides with white low density polyethylene (LDPE) coating. The complete technical data sheet can be download at: procurement.ifrc.org/catalogue.

[4] IFRC, (2009 b) Ferrer C. Serra I., (eds) Ashmore J. Treherne C., *The IFRC shelter kit*, Geneva.

[5] UN Habitat, (2011), *Shelter projects 2010*, Geneva.

[6] IFRC (2007 a), *Fixing plastic sheeting to wood and the ground.*

[7] TYTHE design, *The TARP guide* available at www.tythe-design.com.

[8] IFRC, (2009 b) Ferrer C. Serra I., (eds) Ashmore J. Treherne C., *The IFRC shelter kit*, Geneva.

due to the collection of rainwater on roofs). All this information is also taken into consideration in every shelter training organized by the main NGOs around the world.

The second strategy is based on the gathering of people in large safe buildings e.g. existing collective centres and solid constructions such as gyms or warehouses where it is possible to host the victims for a short period of time, collectively.

FIG. 5.4: EXAMPLE OF PEOPLE ACCOMMODATED IN COLLECTIVE CENTRE

TO ASSURE DIGNITY

Even if only for the first days, living collectively can help people get over the shock of the disaster; damaged buildings result in squalid living conditions when paired with the social problems of forced displacement and overcrowding. As such, collective centres often fail to provide what they should be able to offer: a life of dignity[9]. According to the lifespan of the collective centres, they require different living standards. The flexibility to provide alternative solutions or to address increasing needs is limited. The relative inflexibility of collective centres regarding changing needs is one of the main drawbacks of this kind of solution. Successful experiments to improve living conditions while enhancing privacy within collective centres have been developed by architect Shigeru Ban with an effective system of wall partitions hanging on cubic frames made out of cardboard tubes.

FIG. 5.5: PAPER PARTITION SYSTEM, OTSUCHI HIGH SCHOOL, 2011, SHIGERU BAN

5.1.1. Disposable vs. reusable systems

Rapidly deployable solutions for emergency response cover a wide spectrum of products which range from a 40ft container fully furnished and equipped as a hospital, to the camping tent that can be folded into a backpack. These structures can be sorted according to the number of deployments they are designed for.

FIG. 5.6: CAMPS IN DIFFERENT SCENARIOS

As happens during the "buffer period", presented in Chapter 4, different approaches are used in first and third world countries. Infrastructures like hospitals, communication centres, collective centres or warehouses, due to the high cost and quality of materials involved, are usually designed to be deployed several times both in Western and third world countries.

FIG. 5.7: INTERIOR OF INFLATABLE TENT

On the contrary, for family shelters, two completely different strategies are followed. On the one hand we have family shelters designed for 6-8 people, characterized by height of round 1.8-2.5 m, and a surface area between 28 and 30m^2 (picture 5.6, on the right hand side and picture 5.7). Costs are in the range of few thousand Euros (5,000) and in there, families are grouped together.

These shelters belong to the organization that has distributed them and, after the emergency has passed they are cleaned, folded and stored, waiting for the next emergency to come. The expected lifespan is around 5 years. Meanwhile, in third world countries families are larger and are the basic unit which is considered as a whole. Family shelters are distributed to each family and are designed, on average, to house five people.

FIG. 5.8: INTERIOR OF IFRC FAMILY TENT

9 UNHCR, IOM, (2010), *Collective centre guidelines*, CCCM cluster

As already mentioned, there are guidelines[10] which clearly list all requirements and the living standards that products like this are required to fulfil. They are typically in a range of 16-25m^2 with a maximum height of 2.2 metres in the centre (picture 5.6 on the left hand side and picture 5.8). These shelters are designed to last 1-2 years (most of the time they hardly reach six months), therefore they are deployed only once and then thrown away when damaged. The costs of these solutions are in a range of few hundred Euros (350-600) according to the structural system. A standard version requires guy ropes for the stability of the system while the framed version can be applied easily in urban areas on a hard surface, where anchorage is difficult.

The large differences in quality between the first and the second solutions are evident. On the one hand, living standards and habits among Western and third world countries are completely different. Secondly, in the majority of cases, emergencies in third world countries are much bigger than the ones in the West and the number of people affected is not comparable. Thirdly, Western countries operate through an organized network of local/governmental organizations. Third world countries, on the contrary, are not able to answer crises on their own and, therefore, the management of the emergency is demanded of local or international NGOs that do not have the budget to provide reusable structures.

5.1.2. Ready to use products "all in one"

FIG. 5.9: ALL WEATHER FRAMED FAMILY SHELTER

FIG. 5.10: TAG-NG INFLATABLE TENT

"All in one" products aim to offer the best possible solution at a known price/benefit ratio, answering boundary conditions with certified technical features that have been identified in advanced, before the emergency struck. Ready to use products "all in one" are dedicated according to contingency, are universal and usually neglect to look beyond the emergency phase itself. Whether they are disposable (figure 5.9) or reusable (5.10), these kind of products are closed and their adaptability is limited to the characteristic of a modular system as, presented in Chapter 4.

Solutions of this kind are fixed products with standardized performance. Multiple or additional layers (winterization kits, shade nets) or reinforcement elements (additional anchorages or guy ropes) may be applied in case of necessity and according to climate conditions but these are the only possible modifications.

The role of the user of "all in one" shelters is totally passive. The mounting phase is mainly demanded of practitioners or volunteers and spontaneous modifications or adaptations of the systems to the local environment is not considered an option. Especially in third world countries, spontaneous modification of the given layout of the shelters is a common phenomena, but it usually ends up in worsening or damaging the initial stability or soundness of the product. Correct ventilation and stability against wind are, usually, the most difficult issues to solve in the case of transformation of a shelter.

---

[10] UNOCHA, (2004), *Tents: a guide to the use and logistics of family tents in humanitarian relief*, UN publications

All-in-one solutions approach the problem of sheltering mainly from the product point of view. The process of sheltering is strictly divided into phases with specific products designed accordingly: deployments of these products is decided through a top-down approach with a consequence reduction in the engagement of the locals.

5.1.3. Ready to use systems based on components

Component based solutions are the opposite of the previous category. In this case disassembled simple components are distributed together with guidelines and examples of possible construction can be arranged with those tools. The most widespread example is the already mentioned tarpaulin distribution, which cover the largest number of sheltering interventions, especially in the very first phase.

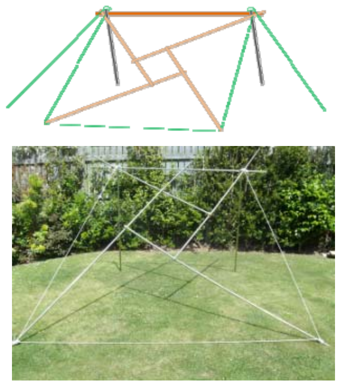


FIG. 5.11: RECIPROBOO PROTOTYPE

Use of textiles in this kind of system has advantages which range from the lightness of the material involved to the reduced volume in transportation. The provision of load bearing structures is mainly requested on site for two reasons: on one hand because standard measures rarely fit the problems of the contingency and therefore may reveal some drawbacks. On the other hand, finding parts of the elements for the shelter on site would stimulate the domestic economy thanks to the application of materials and technologies which are familiar to the affected community.

Main drawbacks of this approach are related to the quality of the dwellings which are set up in this way. It may happen that, due to lack of knowhow about construction, time or resources on site, the shelters that have been deployed and set up to save human lives, became an extra danger. The spreading of diseases or fires is, unfortunately, common, but also deforestation can be an issue.

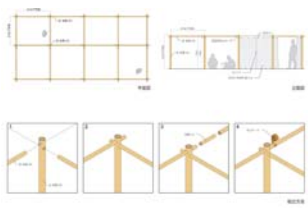


FIG. 5.12: SIGERU BAN PAPER FRAME STRUCTURE FOR COMMUNITY CENTRES

The ReciproBoo concept goes in this direction, focusing on a structure that can be applied to reinforce the stability of the single layer of tarpaulin aims to improve the living standard of simple dwellings set up spontaneously by victims. The frame can either be distributed by NGOs or be purchased or arranged on site directly from users.

Sigeru Ban's paper frame structures go further in this idea. In addition to offering instructions about the assembling of the frames and examples of possible layouts, the material of the structure is carefully selected. Instead of using aluminum profiles which are expensive and, sometimes, end up being sold for money by the refugees (as happened in Rwanda)[11] they are made out of cardboard, at a competitive price, and can be purchased locally or even produced on site.

[11] Mori T.,(2002), *Immaterial Ultramaterial: Architecture, Design and Materials*, Harvard Design School, Cambridge

5.2. Rapidly deployable solution for humanitarian aid

Humanitarian aid uses several rapidly deployable sheltering systems which can be grouped, according to the structural technology, into two main areas: inflatable structures, based on arches and/or linear high- or low-pressure inflatable elements, self erecting thanks to pressurization of the tubes; and rigid metal-framed structures where a series of linear elements are manually assembled on site. In the first case, the cladding fabric is attached to the inflatable elements; in the second, fabric is usually separate from the frame and hung or laid on top of it, once it is assembled.

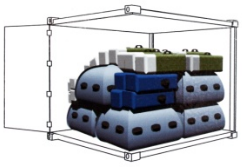


Fig. 5.13: Logistic for TAG-NG inflatable shelters

Fig. 5.14-15-16: Life cube, process of deployment

Fig. 5.17: Facet pneumatic tent as aggregation of linear low pressure tubes

5.2.1 Inflatable structures

According to the area where a disaster has happened, a large number of NGOs make use of pneumatic arch tents of different sizes. Layout is generally standardized and consists of a series of arches connected by the cladding membrane.

These tents are mainly used in developed countries as shelter to host families or groups of people for the first few months after a disaster (as happened in Italy both after the Abruzzo earthquake in 2009 and after the Emilian one in 2012).

Conversely, in third world countries, NGOs such as MSF or other medical organisations use the same technologies to set up emergency hospitals. According to the size of the tent (which varies from 5 to 8m in span) inflatable tents can be used to host patients or used as operating theatres.

Distribution of inflatable tents as family shelters in third world countries would be prohibitive in terms of both cost and logistics. Inflatable tents are mainly used in camps and the set-up is carried out by operators while family shelters are also distributed to locals.

Inflatable tents cannot be compared to the family shelters to be found in the IFRC catalogue. Due to their high cost, these tents are designed to last for several years therefore NGOs dismantle and service them one by one before stockpiling them in warehouses to await the next emergency.

Similar systems, all based on the arcade construction inflated at low pressure (200-350 millibars) have been developed by various companies including Ferrino[12], Losberger[13], Rofi[14], Lanco[15]. Stockpiles of these kinds of solution have been widely investigated and their accommodation within containers has been foreseen too, as shown in the container for the Italian *Protezione Civile* developed by Eurovinil[16].

The combination of a rigid container and an inflatable tent is fully exploited in the "Life cube", a box developed by an American company that can be used as a raised ground floor for the inflatable tent it contains. Transportation on site can be done through a system of

---

12 www.ferrino.it

13 www.losberger-rds.com

14 www.rofi.no

15 www.lanco.eu

16 www.eurovinil.it

wheels that can be attached to the container which is then rolled to the exact location of the installation. Set-up takes around 5 minutes, with two people. The modularity of the system is limited and transport can be difficult in the case of sloping ground however the reusable packaging for the ever problematic question of the floor is more than promising.

Arches are not the only way of defining load-bearing structures. There is the example of the Facet inflatable tent which bases its structural principle on the connection of 12 linear elements that generate triangles and rhombi. This configuration, in collaboration with the membrane's enclosure, gives the structure rigidity. Aggregation of different modules is possible even if the openings and the general dimensions of the tent are, in the configuration brought as an example, rather limited.

Fully inflated domes, like Turtle Tent have also been investigated by the author as an alternative to inflatable shelters for covering large spans. The potential is enormous but manufacturing of an airtight inflatable of large dimension remains a challenge in terms of time and, therefore, cost.

FIG. 5.18-19: HIGH PRESSURE INFLATABLE TENTS

High-pressure inflatable arches substitute low-pressure ones in tunnel-shaped tents offered by makers such as Rofi and Norlense[17]. The advantages of high-pressure structural elements comes from the fact that they are not influenced by temperature changes and therefore do not need periodical infilling. In addition, sections can be drastically reduced (up to 6-8cm compared to the 35cm of standard low-pressure inflatable arches).

From packaging and logistical points of view the advantages derive from a reduction in materials and weight due to the slenderness of the supporting system. In terms of usability, the interior of the tent can be used much more freely thanks to the reduction in obstruction by the arches at the floor level. The drawbacks are mainly related to the inflation systems and valves which have to deal with high pressure and therefore, cannot be repaired locally in the event of failure. The price is also higher compared to standard inflatable tents.

FIG. 5.20: WAREHOUSE WIIK HALL”

5.2.2. Frame shelters

Rigid frame shelters are an alternative to inflatable ones and offer a stiffer solution without worries about the inflation phase and air tightness. The results are heavier in weight, larger in volume when packed, and require between 20%-40% more time for assembling.

FIG. 5.21: PI88 FRAME TENT IN FORCE TO ITALIAN NGOS

In the particular case of Italy, the most common frame shelter being used by the majority of NGOs and local Red Cross organizations is the PI88 model. This solution is comparable to the standard inflatable TAG-NG tent both in terms of covered surface and performance. According to operators interviewed by this author during a visit to camps in Emilia in 2012, both inflatable tents and rigid frame shelters have advantages and disadvantages.

FIG. 5.22: DISPENSARY TENT

An inflatable shelter can be set up by fewer people with less experience but, being in one piece, the total weight of the single bag requires at least four men to carry it from the

[17] www.norlense.no

Fig. 5.23: Multipurpose tent

truck to the final location. A consistent advantage of the inflatable solutions becomes apparent in the case of harsh weather conditions. Setting up of a frame tent when it is raining or at night (when visibility is scarce) can be difficult and take double the time. However, once the steel frame has been assembled, maintenance of the shelter is negligible while inflatables require constant monitoring of pressure which, for large camps, could take as much as one whole morning with one person.

The load-bearing capacity of the steel frame tent is also higher in terms of deformation. It has to be taken into consideration that load on the structural elements of the tent not only comes from external agents (mainly wind) but from actual usage of the tent. Guests use the structural elements to hang up clothes or other personal goods and this load can become significant when multiplied by 6-10 guests.

In the case of third world countries, different frame tents are available according to the function they have to provide. Apart from the framed family shelter presented in paragraph 5.1.2, several frame shelter are listed in emergency item catalogues[18] such as the steel-framed “dispensary tent”, the aluminium-framed (steel connectors) multipurpose tent, the hospital made out of tubular steel by Rubb[19] and the warehouse called “Wiik hall” made from aluminium profiles by O.B.Wiik[20]. These kinds of structures are not usually deployed in the very first phase after an emergency, therefore assembly time is not the highest priority. On the contrary, what makes them successful is the really low effort for maintenance once set up, as mentioned already.

Fig. 5.24: Hospital tent “rub hall”

5.3. Military solutions of rapidly deployable sheltering systems

Fig. 5.25: MPZ inflatable tent by Losberger

The military sector is the larger investor and developer of rapidly deployable sheltering systems from 5 to 50 meters in span. Materials and technologies are in continuous development. Unfortunately. only few of these solutions influence the development of humanitarian products, and the technology transfer remains slow for all the reasons highlighted in Part 1.

Fig. 5.26: Inflatable Hangar, by Eurovinil

In addition to standard inflatable shelters, identical to the ones used in an emergency except for the external covering (camouflage), several brands offer linear element inflatable tents useful to connect different shelters for the setting up of a base camp. Larger products are also available and go up to the 11m span of the inflatable hangar in picture 5.26 with a ratio weight/square meters covered of 6,1kg/m^2.

Fig. 5.27: Warehouse shelter for military purposes by Röder HTS

Even if inflatable technology remains competitive in terms of lightness, larger solutions are traditionally based on rigid metal frames with different sections and materials according to the load they are expected to bear. For example, the Tamm aluminium frame shelter developed by Losberger weighs 224kg for 36m^2 (6kg/m^2) while a comparable inflatable

[18] procurement.ifrc.org

[19] www.rubb.co.uk

[20] www.obwiik.com

tent (TAG-NG at $29m^2$), could easily weigh up to $5kg/m^2$. As for packaging dimensions, a metal-framed shelter requires a maximum length of 2.35m, while inflatable ones can be packed into a maximum dimension of 1.2m, suitable for pallet transportation. It is clear therefore that the real advantage of current inflatable structures, when we are talking about a small/medium span, does not lie in their weight but in the reduced transportation volume and speed of deployment.

FIG. 5.28: ALUMINIUM FRAME SHELTER TAMM BY LOSBERGER

For larger and stiffer structures, the market offers endless options based on a standard aluminium profile which holds the membrane both at the upper and lower edges. When transportation and setting-up phases are critical, the latest development of a carbon hybrid aluminium profile patented by Röder HTS[21] can be used. The main goal of this development focuses on a reduction in the total volume and weight during transportation. At the moment, the producer claims as much as a 50% saving in terms of transportation volume and 30 % in weight, with a consequent time reduction during the assembly phase thanks to lighter elements which can be handled by one person. The extra cost ranges around 20%.

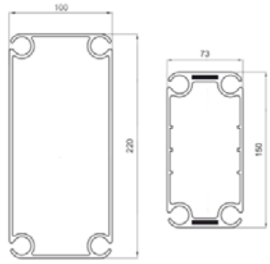


FIG. 5.29: CARBON HYBRID ALUMINIUM PROFILE COMPARISON, PATENTED BY RÖDER HTS

5.4. Structures for leisure

FIG. 5.30: AUDI PADDOCK

Every day, the leisure market demands more appealing structures from a tectonic point of view. Even if standard aluminium-framed tents (with a pitched or curved roof) are the most widespread solution for events, all over the world, the search for new forms and shapes never ends. An extreme result is, for example, Audi's two-storey-high paddock which can be set up in a matter of days. A standard shelter (profiles and connection are the same as the one in picture 5.28, here becomes nothing less than an innovative building with the advantage that it can be dismantled in few days.

FIG. 5.31: DOUBLE MEMBRANE AIR SUPPORTED PAVILION

Leisure applications offer a variety of examples where materials and components are assembled with the clear aim of amusing and stirring the imagination of visitors. This is the case of the large inflatable structures which are used especially for indoor applications or when the required load bearing capacity is minimal. In these cases, a double-layer membrane is kept stable by continuously blowing air through it. These kinds of structure can be considered as something in between common traditional air-halls (for example for the roofing of tennis courts) and pneumatic structures. In the former, the membrane is tensioned due to overpressure between the covered space and the outer environment. Overpressure is maintained by the constant blowing of air into the structure, so the enclosed space cannot be completely airtight. Conversely, in the latter, pneumatic linear elements are manufactured to maintain the overpressure for several days thanks to high-frequency welding and the use of textiles with thick coatings. The result is a heavy enclosure which has to be manufactured carefully, at a higher cost.

FIG. 5.32: AIR CUBE PAVILION

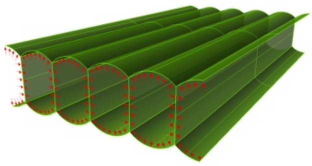


FIG. 5.33: PRESSURE FORCES WITHIN THE DOUBLE LAYER OF MEMBRANE

[21] www.roderhts.com

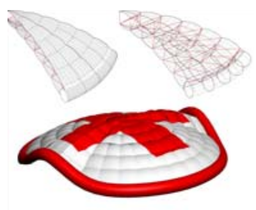


FIG. 5.34: TURTLE TENT 2009

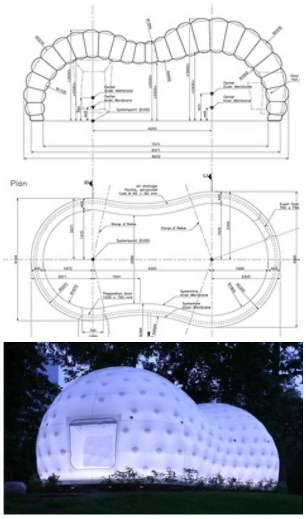


FIG. 5.35-36: THE TEA HOUSE, 2007, KENGO KUMA

FIG. 5.37-38-39: BUBLE DESIGN, MMASA DESIGN STUDIO

The double-membrane air-supported solution (figures 5.30-31) aims to combine the advantages of both systems. The double layer envelope is inflated and the distance between the two foils is maintained through webs or cables. A schematic section is presented in picture 5.32. Layers of membranes, are sewn (instead of welded) together to simplify and speed up the manufacturing process; the thickness of material is drastically reduced, and the problem of air-tightness is offset by the constant blowing of air into the chambers. Even if a free form shape can be manufactured easily, the load bearing capacity of these systems is really low and energy consumption high. Application in emergency can never be straightforward but might be an option in a certain range.

This was the goal of the Turtle Tent developed by this author during his master thesis which consists of a reinforced double-layer dome where the two layers are connected by cables. Stabilization of the whole system is requested from the outer inflatable ring, filled with air and water in the lower parts to keep the structure anchored to the ground.

The double-layer construction system in which two membranes are connected through cables allows the sheltering of a large span in a matter of minutes.

Even more complex shapes have been realized over the last decades using inflatable technology. The most advanced pavilion is the well known “Tea House” by Kengo Kuma. In this case, the stability of the construction is provided by equilibrium between the air pressure and the forces transferred from the two sides of the membrane through the cables which connect them. This principle, beyond the aesthetic results, opens an endless range of applications for the inflatable principle, also in the structural field.

5.5. Implementable solutions

Everybody in the humanitarian sector agrees on the fact that to address needs that arise right after an emergency strikes, solutions must be ready to use. The point of discussion emerges clearly about how this approach should operate. As clearly shown by the examples, all in one, or even plug and play systems are available and have already been in use for years, especially for military but also leisure applications. But the rush of the intervention should be balanced by the careful evaluation of the location where the disaster happened and the level of resilience of the affected community. Alien “closed” solutions might be an option for the first days but may reveal drawbacks in the long term. On the contrary, kits may be too complex and therefore not efficient from the very first days.

From this author’s point of view, among ready to use systems, something is still missing. Inflatable or frame tents or plastic sheeting are solutions too far away to be considered as alternatives. In fact, costs and availability of resources mainly make the decision about which solution should be deployed. This is why part two of this thesis seeks to fill this gap. This author sees potential in the kit approach which might be supported in some way to became effective from the very first hours.

The application of implementable systems right from the beginning of the rescue phases is the approach this thesis wants to support and disseminate through an analysis of the current situation and the application in specific projects, shown in Part II. The advantage would be to combine the rapidity of the all in one approach with the flexibility of a kit that can include components taken from the local context, whether cultural or technological.

An interesting example, in this direction, have been designed by studio MMASA: BuBle, an independent, nomadic flexible dwelling that allows short or long stays according to the kits added to the basic structure which is a metal frame with film walls.

6 LOW- AND HIGH-TECH SHELTERING SYSTEMS

In this author's opinion, the debate on high-tech and low-tech construction technologies and materials is usually discussed from the wrong point of view: the two approaches are often presented as a contrast, one the opposite of the other. Too often, high-tech technologies have been pointed out as the origin of failures in an intervention as the factor which influences the possibility, or otherwise, for local people to actively interact with their dwellings. Moreover, in some cases, high-tech technologies have been identified as the reason why innovation does not enter the humanitarian sector which is prone to conservative approaches. On the other hand, low tech has always been presented as the only solution to let people develop spontaneously and the opportunity to let a community build up its own development based on internal resources and knowhow.

This chapter does not share this opinion and seeks to investigate the topic from a wider perspective, identifying the origins of prejudices about high-tech which is, among humanitarians, synonymous of complex or hard to handle systems, and let the reader think about the paradoxes which currently affect the development of innovation within the sector. The basic assumption of this thesis starts from the idea that high tech means not only materials or technologies but can also involve the process of sheltering at the concept level or at the moment of assembly. From the point of view of this thesis, high-tech solutions can confront the problem of low skills among beneficiaries and local players.

As has been well-presented by Valeria Tatano[1], high-tech is sometimes applied in order to clearly move away from tradition. This is considered one of the biggest misunderstandings in the application of new technologies in architecture: high-tech does not mean that one should forget about tradition and local building construction. On the contrary, high-tech could well be the way to assemble and combine vernacular building technologies with new materials and parts "ad hoc". Application of high-tech in the

[1] Sinopoli N., Tatano V., (eds), (2002) Sulle tracce dell'innovazione : tra tecniche e architettura, Serie di architettura, FrancoAngeli, Milano.

humanitarian sector is not successful if applied "per se" while does offer enormous opportunities when closely linked to tradition. In this way, the value of tradition is not neglected, but sets the basis on which everything should be built to let communities flourish faster and more strongly.

6.1. Sheltering: the point of view of the users

A part of research and experiments (and sometimes applications too) into architecture for emergencies forgets about the most important actors of the process of shelter: the victims. In this dissertation the victims have not been taken into consideration yet however they will be at the centre of Chapters 6 and 7.

THE ROLE OF THE USER

Even though sheltering is mostly seen from the side of those who are providing and organizing its processes , we should, at this stage, reflect on how users deal with the solutions and how they could be included in the process of sheltering too. Low and high tech solutions are two opposite approaches which grant different relevance and responsibility to their hosts, and also identify, in a different way, what role they could have during the period of the stay.

TEMPORARY LIVING "FOR LEISURE" OR "FOR NECESSITY"

In the world of lightweight construction, we can identify different users of sheltering products and they can be sorted into two main groups. On the one hand, there is the case of temporary living "for leisure", when users spontaneously decide to undertake extreme experiences for example, in the case of sports activities in remote areas. On the other, there is the case of temporary living "for necessity" or "for survival", for example, after a natural disaster[2].

Although in this essay the focus will be on the second case, the first one cannot be neglected, indeed it could be a precious source of inspiration. Both kinds of temporary living conditions are strictly related to each other and some technologies or devices, mainly designed for the first use, can solve some of the problems of the second one too. However, this knowledge transfer must be carefully controlled.

There are several technological risks in the application of the solutions designed "for leisure" in cases of emergency which go from the comfort level, to complexity in assembly or issues relating to the problem of repairing the technology, for example, in case of damage (the cost of spare parts, availability of materials, the knowhow required and so on). For all of these reasons, high-tech solutions are usually avoided and substituted by simple robust solutions where "low-tech" prevails, offering certainties based on past experiences of practice in the field.

Additional risks are a matter of approach too: when temporary is "by choice", users are willing to live temporarily and are prepared to face up to their current situation: the

[2] Giurdanella V., Zanelli A., (2006), *Lightweight, adaptable and reversible construction: sustainable strategies for housing*, Adaptables 2006. International Conference on Adaptable Building Structures, Eindhoven, The Netherlands

experience is meant to be limited in time and taking care of the shelter is part of the game too.

In the second case, users are *forced* to live in temporary dwellings and, sometimes, cannot predict how long that experience is going to last. This will not depend on their own will and therefore social and cultural acceptance become crucial: sheltering technologies need to serve the end users and therefore, if possible, they should adapt to them, in accordance with the local context.

If the final goal is to put users in a condition to become familiar with their environment, lightweight architecture needs to adapt and take inspiration from construction methods which are familiar and common in the specific context enhancing, in this way, "ownership" of the solutions.

Here the question arises spontaneously: is it possible to be high-tech while applying local materials and tradition? The answer relies on the design: if an innovative design is able to learn from the vernacular tradition and develop standard sheltering methods in a more efficient way thanks to the evolution of science and technologies, then integration of high and low tech is possible.

Together with the concept of temporality, as a watershed between the two ways of temporary living there are the other four concepts mentioned in Chapter 3.

First of all, flexibility in the structures–intended as their ability to adapt to the different environmental requirements, changing demands and climatic conditions–represents the major concern from the end-user's point of view. According to the time span of the stay, this performance must be appropriate .

Secondly, portability of the solutions and efficient packing and shipping configuration in cases where transportation is an issue, represent the main worries from the practitioners' point of view.

Thirdly, a minimum and efficient use of material able to offer the best performance to the largest number of people is the main goal of NGOs and local authorities who have to shelter all victims with a limited amount of money.

In conclusion, a sustainable design that envisages how materials/components could be recycled/reused when the emergency phase has passed, their lifetime, their local availability and their maintenance costs needs to be considered too.

Fig. 6.1: Lightweight roof and mosquito net for hiking

Fig. 6.2: Ice-fishing shelter

Fig. 6.3: Instant housing

Fig. 6.4: Hanging tent

Fig. 6.5: Ultra lightweight camping tent with bending active supporting rods

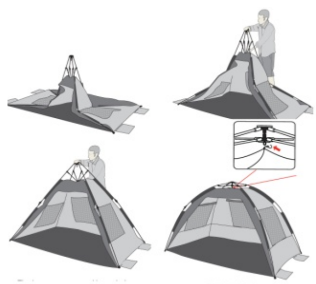


Fig. 6.6: Rapid deployable camping tent based on the umbrella concept

6.1.1. Sheltering for leisure

This represents the most sophisticated and elegant temporary solutions, able to answer to new needs for housing, nomadic living, leisure and sport.

High-tech materials and systems have been specifically developed and applied in these cases. Two opposite solutions are possible. In the first (which is not shown in the pictures), several devices such as caravans, tents or boats are already on the market and these are able to satisfy the desire for freedom in an efficient way. These solutions can be similar to everyday dwellings but take inspiration from the word of cars, planes or other more

FIG. 6.7: THE ECO TENT: DETAILS

FIG. 6.8: THE ECO TENT: PROTOTYPE

FIG. 6.10: RELIEF YURTA TENT PAKISTAN

FIG. 6.11-12-13-14: EXAMPLES OF LOW- TECH SHELTERS

advanced fields. As a result, these dwellings are not only houses but become a luxury concentrate of devices, that include comfort and innovative design.

On the other hand, extremely minimal shelters are also an answer. These lightweight shelters are required by users who are seeking fun and adventure. To sleep in extreme weather conditions in a forest (Figure 6.4) or on the top of a mountain, or after a 100km bike tour (Figure 6.3) or again, to stand still on a frozen lake for fishing (Figure 6.2), a high performance from the material and technology points of view is required.

These solutions are far from being comfortable or luxury: only efficiency matters. Innovation in materials is the core of the development in these kinds of structure but simplicity is usually the main driver: the adaptation of the principles of tensile structure (Figure 6.1), the use of the bending stiffness of glass fibre rods to stretch the walls (Figure 6.2) or to tension the canvas of the tent (Figure 6.5) or the application of the basic umbrella principle to set up a shelter in few seconds (Figure 6.6) are only some examples.

6.1.2. Sheltering in case of necessity

Fig 6.9: The Eco tent

Sheltering, in this case, responds to an urgent need for protection and safety, following natural disasters or war emergencies, and offering humanitarian and sanitary aid.

The main goal is to provide an immediate response to the crisis while dealing with social, economical and technical issues. The solutions offered in this scenario need to be simple, effective and ready to assemble; they should be fast to set up, easy to maintain and repair, and easy to deal with in all phases of an emergency.

The final product should provide the highest level of comfort in relation to the amount of resources available: in simple words, it needs to be cost effective.

New materials or high-tech solutions should be carefully tested before their application especially as regards knowhow and social acceptance by the final users. In addition, these solutions need to let people feel safe and the population should recognize them as “their homes”.

Some big issues derive from the fact that these solutions need to be designed and adapted to satisfy different users with different requirements and backgrounds: from children to grandparents and from educated to illiterate.

Sheltering systems used in post-emergency occasions have some specific features that can vary according to the environmental conditions or the kind of emergency they have to cope with. In any case, in the case of “sheltering for necessity”, among all the features already mentioned in the paragraphs above–which are valid for leisure too–two properties are more important than the others: i.e. they should be easy to deploy (both in terms of transport and set up) and they should be cheap.

These two basic characteristics lower the standards of the dwelling and this is the reason why, sometimes, as an emergency shelter, NGOs use products that were not designed to shelter humans such as exhibition pavilions, temporary roofs, coverings for sport centres, warehouses, army facilities etc., etc..

To ensure an acceptable living standard, a balance between those two features and more traditional characteristics of a dwelling such as air comfort, architectural appeal, or usability) is required.

Of course, to find the right balance is not an easy task, and here is where high-tech may contribute by offering better solutions.

6.2. High-tech solutions: pros and cons

The latest developments in materials and technologies derived for military or sport applications together with ones deriving from the world of sheltering for leisure offer an endless source of inspiration.

FIG. 6.15: PAPER EMERGENCY SHELTERS FOR UNHCR - BYUMBA REFUGEE CAMP, RWANDA, 1999

Looking at all these kinds of solutions one might think that the problems of sheltering in emergency can be solved much more easily than years ago, however their positive impact on the emergency is not as linear as it seems. The facts and figures tell us the contrary: the number of natural or human-made emergencies is growing, the number of people affected has increased accordingly and humanitarian response often still fails (see Chapter 1).

In addition, experiences from shelter assessments tell us that most advanced *products* might offer consistent benefits in the short term, when the focus is about saving lives, but the development of a community and its coming back to normal life is a completely different matter and mainly involves *processes*.

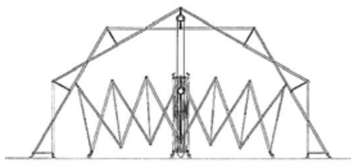


FIG. 6.16: FOLDABLE FRAME FOR SHELTERS

To become fascinated by advanced technology during the process of developing an innovative sheltering product might be tricky. The biggest error one can make is to assume that one particular technology or one specific material would be able to solve all problems related to sheltering.

As already mentioned in the introduction and in Chapter two, sheltering should be considered as a process rather than as a product and due to the fact that demands are constantly evolving, there may not be any technology able to answer all requirements at the same time.

The complexity of sheltering activities requires a systematic approach where technologies and materials are only a small part of a complex picture which is constantly evolving: variable timing is crucial and, therefore, Chapter seven is dedicated to this topic.

In addition, the introduction in the field of new variables deriving from new materials and technologies needs to be controlled carefully: innovation will generate, by definition, consequences that also need to be taken into account in such a way as to limit the increase in risk.

HIGH- VS LOW-TECH: A MEANINGLESS CONTRAST

In any event, this thesis wishes to support the idea that contrast between high- and low-tech has no value and that, on the contrary, they can merge in an effective solution.

Starting from the assumption that any high-tech product "*per se*" will never find an application in the humanitarian sector, and from the fact that advanced materials and technologies developed in the last decades might greatly improve the living condition of victims, the role of the researcher is crucial. He/she needs to act as a filter and select the most successful innovations and combine those systems which have positive impacts, not only in the short but also in the long term.

6.2.1. Colonialism of emergency and support of local economies

FIG. 6.17: CITY CENTRE OF L'AQUILA: 4 YEARS AFTER THE EARTHQUAKE

FIG. 6.18: PROGETTO C.A.S.E., NEW NEIGHBOURHOOD BUILT UP AFTER THE EARTHQUAKE

The time period after an emergency is a delicate moment for any community but is even more critical for those countries which have a low level of resilience and need external help for a long period. The humanitarian intervention of NGOs or in the worst cases, even military corps may aggravate the equilibrium of an already fragile community affected by a disaster.

If on the one hand, this risk is most likely to affect third world counties, whose habits, culture and life can be easily influenced and subverted according to the will of the external "help", it can happen in Western countries too. And the consequences of these choices may affect the community for decades.

This author got to know the Italian situation first hand after the earthquake at L'Aquila in 2009: new towns were built within a few months after the earthquake struck but still, after four years, the city centre of L'Aquila is closed and the majority of the buildings have not been repaired. The city has already been named the "ghost city" and no clear plans for reconstruction have been indicated.

The citizens of L'Aquila have been transferred to brand new districts and if, on the one hand, they have been provided with new houses, fully furnished, they have lost their own city together with their lifestyle and habits.

In this case, the response of the local authorities was fast. In a few months all the victims were relocated or new houses were built. But it may well be that economic interests drove the construction of new lots instead of the reconstruction of the old city. At any rate, a complete analysis of the emergency management of the case of L'Aquila is difficult and is not the goal of this dissertation.

In the same way, but on a bigger scale, in third world countries the main risk of the application of alien technologies may turn into a neo-colonialism of emergency.

As presented in the introduction, the goal of humanitarian assistance is to bring a community back to a state of equilibrium and put locals in the condition to achieve development based on their own resources. otherwise an emergency will end in such a way that the community will always depend on external help.

Sometimes, keeping communities dependent from external factors may be a political or economical leverage which is definitely against the principle of humanitarian assistance presented above.

On the contrary, the application of technologies and materials which can be purchased or arranged locally, together with designs based on vernacular construction systems which are easily accepted by the victims themselves is a clear step towards independence and an important input for the local economy.

The possibility to transport certain shelter processes and products influences the chances of a community coming back to independency as fast as possible, while the enforcement of particular solutions which are conceivably more efficient from a technical point of view, but are far removed from the local context and culture, would create severe fallouts in the long term.

6.3. Low- and high- tech building components

FIG. 6.19-20-21: FLAT-PACK BUILDING BLOCKS, DROR BENSHETRIT, 2011

Building components applied in an emergency can also be low- or high-tech according to the availability of resources at the moment of construction and the performance these components should fulfil.

From a general point of view, as mentioned in paragraph 6.2, a low and high-tech contrast has no meaning, a theory does not help to sort out the best solution. Only when the problem is specific and the context is clear, is it possible to identify the most useful option.

It may happen that complex spatial connections are traditional structures for a particular community, for example, made out of bamboo while the same “low-tech” solution cannot easily be applied in other contests where it would appear “high-tech” due to lack of knowhow or scarce availability of materials.

Low-tech systems, therefore, vary according to the context we are dealing with. Concrete walls or metal frame construction systems are both low-tech for Western countries while they may be difficult or even impossible to apply in an emergency situation. For this reason, at the moment of the choice, humanitarians find themselves at a crossroads: on the one hand technologies and materials which are considered low-tech from a “Western” point of view, may be “exported” to answer the need of victims in danger or, but on the other, new solutions might only be found thanks to the application of local materials.

However, exporting materials implies the transportation on site of mass and volume and this is mainly related to products. On the other hand, the exporting of ideas and technologies is much more effective: the assembly methods, the combination of simple elements to reinforce structures and the careful control of forces–for example in the foundations– are processes which may be high-tech in their concept but can be put into practice using local materials available on site, at the moment of the disaster.

The author knows that an exhaustive analysis of the different possibilities of applying high- or low- tech principles in an emergency would require much more than a few paragraphs, however to better understand the variety of solutions and opportunities in this field, a few distinctive examples presented according to different subsystems will be illustrated below.

In each case, a selection of examples will be presented to try to identify the impact low- or high- tech technologies will have not only on performance but also in the long term.

6.3.1. Roofs and cladding

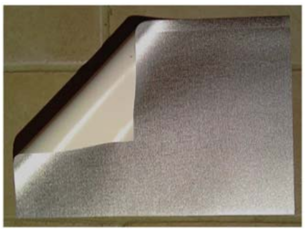


FIG. 6.22: PES-PVC COATED ON COATED ON ONE SIDE WITH LOW-E TREATMENT

Materials available for cladding and roof systems range from textiles to steel sandwich panels heavily insulated with mineral-wool, to cardboard sheets or polypropylene panels or block-wall systems.

Among the textile solutions–which are the focus of this dissertation–the range of properties of canvas is huge. This goes from the well known tarpaulin or poly-cotton textile up to polyester, PVC-coated high-strength fabrics with a low-emission top coating (commercially named "Low-E") which can be installed on the inside to prevent heat losses in winter and overheating in summer.

Advanced performance, especially in the field of textiles is crucial: these characteristics may compensate for properties which are usually related to massive materials, for example, improving thermal or acoustical performances.

Moisture and fungi control also become crucial to prevent the spread of diseases. Starting from the assumption that fabrics are accepted all over the world and can be processed almost anywhere, technical textiles are welcome as long as the benefits justify their cost.

A particular consideration needs to be given to those components made out of 100% recyclable or biodegradable materials, and these characteristics may be found in both high-tech and low-tech components.

FIG. 6.23: TARPAULIN CLADDING SYSTEM

FIG. 6.24: WALLS MADE OUT OF SAND BAGS

FIG. 6.25: POLYPROPYLENE TWIN WALLED FLUTE BOARD

FIG. 6.26: CARDBOARD SHELTER

6.3.2. Load bearing structures

A load bearing structure can be achieved through different means.

On the high tech side we can list inflatable airframes, rigidized either at high- and low-pressure; bent composite frames follow: these are largely used in camping activities but, if the material can be easily transported on site, their application is unquestionably efficient and effective. Metal frames together with structures made out of local materials like wood or bamboo which can be collected on site, may be considered low tech.

FIG. 6.27: AIRFRAME BASED ON ARCHES

Metal frame shelters differ according to the load bearing resistance over weight and the durability of parts. The majority of them are based on linear elements (tubes or plates) connected together by special joints. Yet other options are based on rectangular frame constructions which became walls and load bearing structures at the same time, as in the case of the Earth House System (Figure 6.28). In this case, the frames can be filled or covered with any material so as to easily create a cladding system too.

A load bearing structure based on mass is the low-tech alternative to this frame system: structures based on compressed earth or rubble blocks are common. Rubble Houses (Figure 6.31) are just one example, where rubble from collapsed buildings is recycled to build up the new walls arranged within steel wire cages.

FIG. 6.28: STRUCTURE BASED ON PLANE RECTANGULAR FRAMES

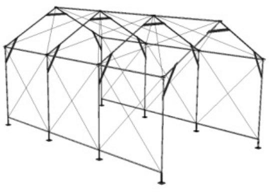


FIG. 6.29: FRAME BASED ON LINEAR ELEMENTS

FIG. 6.30: STRUCTURE BASED ON BENT ELEMENTS

FIG. 6.31: LOAD BEARING WALLS MADE OF RUBBLE

The joints and connections of linear elements are usually the most critical part of frame shelters and are essential for top class operation of the whole system. This is why research and development has always focused on simple, flexible and resistant joints either for tube and plate frames.

FIG. 6.32: BAMBOO PLUG AND PLAY JOINT

FIG. 6.33: TRADITIONAL BAMBOO JOINT

FIG. 6.34: MALE ADAPTABLE CONNECTION JOINT FOR FRAME SHELTER

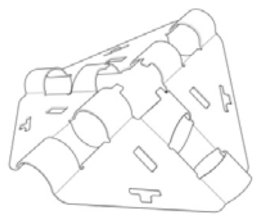


FIG. 6.35: FEMALE JOINT FOR STEEL FRAME SHELTER

Other approaches have been investigated: female or masculine holders but also adaptable (moveable) and multiple (when several elements need to be attached to it) systems have been produced. At any rate, flexibility needs be limited within certain values and this is why, learning from traditional joints one can see how simple (and low tech)these connections can sometimes be.

6.3.3. Foundations

FIG. 6.36: PAPER LOG HOUSE SHIGERU BAN

Foundation are the most critical part of lightweight constructions. The whole stability of the system depends on the stability of the anchoring system. Being the most expensive part of the whole construction, anchoring must be judged not only based on performance and costs but also in relation to the expected life span. Aluminium, galvanized or even stainless steel elements are present on the market.

Foundations can also be arranged through dead weight, as happens in the Shigeru Ban Paper Log house project where the foundations consist of donated beer crates loaded with sandbags. The examples clearly show how in the subsystem foundation, the design and the geometrical arrangement are more important than the materials and technology being used.

FIG. 6.37: PEGS

FIG. 6.38: STEEL AUGER AND ALUMINIUM ANCHORS

FIG. 6.39: BEER CRATES AND SANDBAGS

6.3.4. Connections

Connectors and joints can be made either with local materials or by means of specifically designed elements. Fitting and nails have been investigated extensively by NGOs and have been carefully included in NFI catalogues. The low-tech nature of successful components emerges in this field: repairing and maintaining a shelter is a progressive process and needs to be done by the final users directly, therefore standard tools and components should prevail, or at least, their application must be taken into account. For example, frames where is not possible to drill holes or hammer nails might prove useless.

FIG. 6.40: FITTINGS AND NAILS AVAILABLE ALL OVER THE WORLD

FIG. 6.41: CONNECTOR FOR TARPAULINS

FIG. 6.42: STONE AS REINFORCEMENT FOR TARPAULINS AT CONNECTION POINTS

FIG. 6.43: STRAPPING

6.4. The particular case of Tensairity®.

Inflatable structures are now common and widespread especially for covering sports and leisure infrastructures.

Air-halls remains the most efficient way, in terms of time and cost, to shelter sports facilities with the minimum amount of material. For the same reason, inflatables fascinate the world of humanitarian aid too: lightweight, ready to use, self sustainable solutions which can be mounted by a bunch of people with no particular skill might well be a solution to save a large number of lives.

On the contrary, the facts tell us that application of inflatable structures in an emergency is rare. If in Europe or the USA most of the shelters are based on the inflatable tunnel-shaped tent (used by MSF and local Red Cross), in developing countries these solution are not applied due to their cost but also to cultural and technological limitations. Unfortunately, these countries are the ones most in need of rapidly deployable shelters able to protect victims from rain and sun from the first few days.

FIG. 6.44: MONO LAYER AIR HALL, WEIGHT OF THE STRUCTURE: 1 KG/M²

The reasons for these difficulties are several and have been identified throughout this dissertation and are mainly related to culture and acceptance.

In point of fact, technological limitation, are not that much of a problem anymore. Repairing an inflatable is no different from fixing a flat tyre: the tools are available almost all over the world or, at least, everywhere there are bikes. Thus, the high-tech nature of inflatable structures is mainly related to the inflation system (e.g. blowers or compressors) which, in the case of low pressure, may be substituted by hand pumps. In reality, inflatable systems are not applied in emergencies mainly due to suspicions that they would prove “alien” in the local context and due to doubts that they can be integrated in the “transitional settlement” approach which will be discussed in Chapter 7.

The innovative principle of Tensairity®[3] may be the answer to those needs by offering the combination of a rapidly deployable inflatable solution with durability and the possibility of implementing the construction of a transitional dwelling thanks to reinforcements which can be found locally.

Tensairity® is the latest development in terms of high performance inflatable beams based on the principle of the stabilization of slender compressed elements through the use of air. The result is a light foldable system which can be transported easily and can be much more rigid than other inflatable beams, with lower pressure. Tensairity® consists of two parts: the inflatable which has to be transported on site after the disaster and the linear elements for reinforcements which can be found locally. These elements can be the seed of a new construction towards the transitional and development phase.

As already mentioned, inflatable structures are extremely promising when transportation and set-up time are an issue. They can be packed into small volumes and do

[3] Luchsinger R.H. et al. (2004). *The new structural concept Tensairity: Basic Principles*, in Progress in Structural Engineering, Mechanics and Computation, ed A. Zingoni, A.A. Balkema Publishers, London.

not require much effort to set up. Conversely, they do require an air blower and their shapes are usually squat and limited. The most advanced example of inflatable architecture is the Airtecture Hall (1999): this is a mobile, rectangular, meeting and exhibition space that uses a number of innovative high-pressure structural systems.

FIG. 6.45: AIRTECTURE HALL, 1999

It consists of three main elements:

1) air-filled-y-shaped columns, tensioned by cables and a series of linear pneumatic “muscles”;
2) air-filled flat panel walls; and
3) air-filled roof beams.

FIG. 6.46: GARAGE PARK MONTREAUX, 2004

The pneumatic “muscles” that help to stretch the building are active structural members that can be automatically loosened or tightened depending on external wind pressure. However, the Airtecture is an exception. Most of the inflatable technology used in an emergency is far from being innovative and nothing really new has cropped up since the very first applications.

FIG. 6.47: PLANCHAMPS SKIERS BRIDGE, 2006

A big step forward in the development of inflatable technology might be made by the promising research into Tensairity® since this can combine the advantages of pneumatic structures by reducing the section of the air beam at low pressure. Moreover, general doubts about the safety of inflatable system (mainly related to deflation or loss of pressure) are avoided since Tensairity® includes steel elements, which can be dimensioned to withstand the permanent loads even in the event of a pressure loss.

FIG. 6.48: OBSERVATORY TENERIFE, 2008

Even though the Tensairity® system is highly effective, combining cables and struts around the air chamber, some of the advantages of pneumatic systems are lost. In fact, this author believes that having rigid elements coupled with the air beam may be the weak point in this construction principle from the logistical point of view for several reasons.

First of all, the maximum length of the steel girder is limited by the means of transportation and by the length the industry can actually provide. Secondly, the Tensairity® beam can be dismantled but it cannot be folded like a conventional pneumatic element.

FIG.6. 49: TENSAIRITY® MATTRESS, 2010

Thankfully, the latest research[4] has proved the possibility of substituting the steel girder with a collapsible element so that the whole element can be folded and stored in a simple box. In this way, it would be possible to transport the whole element in a much smaller volume thereby reducing cost and time.

FIG. 6.50: TENSAIRITY® ARCH, 2010

Moreover, the setting up of inflatable structures remains fast and simple and neither cranes nor scaffolds are required. Examples of this application can be found in the “garage park” by Motreaux, (2004) and in the Tenerife observatory (2008). Huge spans are the best application for Tensairity® structures: temporary infrastructures like roads or bridges can be set up in just a few hours. This is the case of the “Planchamps Skiers bridge” (2005) with its 56m span.

[4] De Laet L., Luchsinger R. H., Crettol R., Mollaert M. And De Temmerman N. (2009) *Deployable Tensairity®* Structures. Journal of the International Association for Shell and Spatial Structures, Pellegrino (eds.), vol. 50, n. 2, pp. 121-128.

Some recent studies have demonstrated that beams are not the only structural elements that can be made with Tensairity®. Mattresses or arches[5] are also possible, as will be shown in detail in part two.

6.5. High-tech in concept but low-tech in construction

The humanitarian sector needs solutions and alternatives but an effective answer is not the high-tech one "*per se*". Moreover, it has been clarified that only a few solutions are high-tech by definition but they might turn out to be, depending on the area and disaster phase they are applied in.

Therefore, for each situation, different solutions with different levels of technology need to be taken into account, keeping in mind that humanitarian help cannot make the mistake of becoming an exclusive activity. The openness of the systems in use and the collaboration of third parties with local players play a key role in the success of the sheltering process, stimulating the local economy and strengthening the sense of ownership of the new dwellings.

Moreover, the process usually does not end when all the people have been sheltered but goes on for several years after the emergency has ended, through a process of development which should be carried out by the affected community autonomously.

To ensure the most rapid development of the community affected by a disaster, local players need to be placed in a condition to become familiar with the technology in use and to be able to provide the right material for repairing the old construction and to maintain the new ones. For this reason, as always highlighted by humanitarian actors, the concept might be to look for high-tech solutions but their application needs to remain within the capabilities of the local community and therefore, in this respect, "*low-tech*". However, ideas are neither high- nor low-tech: ideas either work or they don't and innovation comes from the former.

[5] Crettol R., Gauthier L. P., Luchsinger R. H. Vogler R, (2010), *Tensairity Arches,* Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2010, Shanghai

7 TIMING AND EMERGENCY

Time is a key factor in emergencies[1] *and it influences the success of an intervention from three different points of view: firstly the rapidity of the intervention itself; secondly, the timeline of progress in victims' living conditions, from a state of emergency until the re-establishment of normality; and thirdly the degree of temporality of the solutions or strategies applied which are deployed for a specific and (usually) limited period of time.*

Emergency can be defined as a "sudden and usually unforeseen event that calls for immediate measures to minimise its adverse consequences"[2]*. The concept of time is at the basis of this definition which clarifies the unpredictable nature of the emergency and the necessity for a prompt response. For this reason, besides the importance of an immediate response, the time factor not only enters after a disaster has occurred but should also be taken into account before it happens: being prepared for a disaster is probably the most important phase because effective results in these areas creates immediate benefits during the disaster whose impacts are reduced.*

The progress of the timeline in emergency is defined by phases which differ in name and number according to the disaster and the actors leading the process. These phases are the basis of the definition of the process of emergency management but, of course, of sheltering too. Addressing the specific needs at the right phase of the emergency, would dramatically speed up the development of the affected community. The biggest mistake would be to consider the emergency timeline linear: on the contrary, minor emergencies emerge on the way and therefore the timeline must be liquid and adapt to the changing variables.

The concept of "temporality", intended as a transitional phase, sets the standards and the condition of the temporary living quarters which victims may adapt to. What is

---

[1] Osman A. and Sebake N. (2010) *"Time" as a key factor in design and technical decision-making: concepts of accessibility, affordability, participation, choice, variety and change in the South African Housing sector* in Human Settlements Review, Volume 1, Number 1

[2] See appendix 1

standard is always the trade-off between the rapidity of the deployment, the resources available and the expected time for the solution to work. The progressive nature of the solutions in the direction of development, consists in the possibility to upgrade, improve and modify solutions according to the contingency. The possibility of having solutions which can evolve over time thanks to the inputs and contribution of locals is the direction where the humanitarian sector would like to go. Therefore, the largest source of inspiration for emergency architecture is temporary/seasonal structures for sports, exhibitions or shows which will be taken as inspiration in the following paragraphs.

7.1. Different speed and timing of intervention

VERY FIRST HOURS

The first few hours after an emergency strikes see the intense and stressful activity of life saving. It cannot be identified in advance how long this phase will last but, according to the magnitude and location, this could range between a few hours to even a few days.

Structures to support this activity are improvised hospitals or other facilities to house injured people. Basic roofs able to shelter and protect people from rain or sun are also crucial in this situation. These kinds of structure also have a role of offering a sense of protection and identifying safe areas where people can gather.

Operating theatres are usually set up in existing buildings, if possible, or even in the open air in case of necessity. Infrastructures come along in this very first phase: mobile hospitals, communication centres, command centres but also community shelters where coordination can be arranged. Facilities to support the activities of practitioners are also arranged. These solutions may be set up in few minutes and can work autonomously to be able to offer their services in every condition. The key features of these solutions are also the packaging constraints which are supposed to allow shipment even in remote areas.

LATER STAGE

When the priority of saving missing victims has passed, attention is focussed on those who have lost their belongings and do not have a safe place to stay.

Vulnerable people such as children or the elderly are primarily taken into consideration. Only in the second instance, are families sheltered. At this stage, some time affect the decision-making process: displacement of people to camps or scattered shelters close to what remains of their dwellings implies a different time of action and opens two opposite scenarios.

PEOPLE ARE DISPLACED

When people are sheltered in camps, the use of shelters is meant to be limited in time. Camps are set up to offer “new cities” while the real ones are repaired or rebuild. As soon as the construction has finished, people abandon the emergency solutions to come back to their properties. Unfortunately, the time span of this process can vary from a few months up to years or, in the worst scenario, may never end and, therefore, temporality is disobeyed.

In any event, even where the life span remains short, the solution adopted should take into consideration the climatic conditions and their variations according to the seasons. Adaptability in the solution is, therefore, crucial and needs to take into account the opportunity to introduce extra components to improve thermal comfort but also the structural integrity of the solution.

In the poorest countries, it may happen that these solutions become through progressive implementation over time; permanent solutions with a higher standard compared to the previous dwelling.

On the other hand if solutions cannot be upgraded, they may easily become the slums of the future with consequences of social danger too. These kinds of solution are the so called "transitional shelters" and will be presented in depth in the following paragraphs.

PEOPLE REMAIN CLOSE TO THEIR BELONGINGS

An opposite scenario appears when people are not displaced but remain close to their dwelling and belongings either to rebuild or protect them. The timing of the intervention, in this case, is slower and is based on the service of every single component. Even a few elements can be useful and effective in repairing the existing dwelling and every component can be included in the reconstruction of the house that will become a permanent one. Implementation is therefore seen in a more progressive way, and every component has a different value and is selected according to the expected lifespan it will require on site. Structural elements, cladding systems, floor foundations need to be designed and applied based on the possibility of further implementation.

7.2. Time phases of an emergency

TEMPORAL OR FUNCTIONAL PHASES OF THE EMERGENCY

Emergency phases can be intended either as temporal or functional. The problems of the temporal interpretation of phases is the risk of considering one phase as a linear consequence of the previous one. Function consideration of the phases is more flexible: they are described as "activities" which can overlap, in case of necessity. In this chapter both interpretation will be taken into account.

Definition of the phases of emergency is useful to clearly define the priorities at every particular stage after a disaster occurs and, therefore, to be able to offer the best solution at the right moment.

Understanding the disaster phases currently adopted by NGOs is complex because different definitions can be found in literature and every NGO has its own nomenclature. The division of the phases in this chapter is the result of a review of the literature but also discussions with operators from the sector and personal interpretations too.

FIG. 7.1: FIVE PHASES OF EMERGENCY MANAGEMENT

As reported in Baird (2010)[3], the concept of "phases" has been used since the 1930s to help describe, examine, and understand disasters and to organize the practice of emergency management. The literature offers several examples of different researchers using five, six, seven, and up to eight phases. (Neal, 1997)[4]. At the moment, it is hard to define a standard

[3] Baird M. E., (2010), *The "Phases" of Emergency Management*, Prepared for the Intermodal Freight Transportation Institute (IFTI), University of Memphis

[4] Neal, D. (1997), *Reconsidering the Phases of Disaster*, International Journal of Mass Emergencies and Disasters, Vol. 15, No. 2, August, 239-264

division in phases even if the majority of studies refer to four phases: mitigation, preparedness, response and recovery mainly represented as circular or, according to FEMA 2006, five phases which are presented more as parallel activities, with three of the five (prevention, preparedness, and mitigation) spanning the entire period from pre- to post-incident (Figure 7.1).

HOT AND COLD PHASES OF THE EMERGENCY

To simplify matters, a preliminary analysis can divide phases of emergency into two macro areas: hot and cold phases of emergency. The hot phase deals with the emergency response and includes the warning of the population at risk to save life and properties but also the crisis management together with the mapping of damage, forecasting evolution and further danger, and providing support to relief staff to facilitate access and communication.

On the other hand, is the cold phase which can be seen as the periods preceding or following disasters. In this phase the focus is on two macro areas: risk reduction, which means controlling vulnerability in terms of measures put in place to reduce impact e.g. land use practices, risk maps, checking of dams/dykes and damage assessment which includes reconstruction and long term planning.

The cold phase and the hot phase are not actually separate. Effective preparation and mitigation during the cold phase would reduce risk and damage which arise during the hot one. The cold phase is characterized by availability of time and low stress level but the variables to take into consideration are endless. On the other hand, hot phase works on shortage of time and focuses on the contingency where it is difficult to keep in mind the bigger picture. But unfortunately, decisions taken during the hot phase greatly affect development during the cold one.

Starting from the work of Baird who tried to bring order to the confusing glossary of names referring to the phases of emergency management, in the next paragraphs, the author wants to address specific definitions of phases related to sheltering.

7.2.1. Phases of emergency management

There are many schemes which represent the phases of emergency management (e.g. figure 7.2, taken from National Earthquake Hazards Reduction Program, Introduction to emergency management.). Many of these graphics show the interaction between the different phases which are not consequential but mostly overlap. This clearly shows that critical activities frequently cover more than one phase, and the boundaries between each of them are seldom precise. Most schemes also emphasize that important interrelationships exist between all the phases. As mentioned before, “mitigating” flood damage by restricting development in a flood plain will reduce the problems in “responding” to flooding.

FIG. 7.2: FOUR PHASES OF EMERGENCY MANAGEMENT

Taking as a main reference the division of emergency into five phases from the DHS, Federal Emergency Management Agency (FEMA), National Response Framework Glossary/Acronyms as reported in Baird, 2010, definitions of them are listed below.

Mitigation

Activities providing a critical foundation in the effort to reduce the loss of life and property from natural and/or manmade disasters by avoiding or lessening the impact of a disaster and providing value to the public by creating safer communities. Mitigation seeks to fix the cycle of disaster damage, reconstruction, and repeated damage. These activities or actions, in most cases, will have a long-term sustained effect.

Prevention

Actions to avoid an incident or to intervene to stop an incident from occurring. Prevention involves actions to protect lives and property. It involves applying intelligence and other information to a range of activities that may include such countermeasures as deterrence operations; heightened inspections; improved surveillance and security operations; investigations to determine the full nature and source of the threat; public health and agricultural surveillance and testing processes; immunizations, isolation, or quarantine; and, as appropriate, specific law enforcement operations aimed at deterring, pre-empting, interdicting, or disrupting illegal activity and apprehending potential perpetrators and bringing them to justice.

Preparedness

Actions that involve a combination of planning, resources, training, exercising, and organizing to build, sustain, and improve operational capabilities. Preparedness is the process of identifying the personnel, training, and equipment needed for a wide range of potential incidents, and developing jurisdiction-specific plans for delivering capabilities when needed for an incident.

Response

Immediate actions to save lives, protect property and the environment, and meet basic human needs. Response also includes the execution of emergency plans and actions to support short-term recovery.

Recovery

The development, coordination, and execution of service- and site-restoration plans; the reconstitution of government operations and services; individual, private-sector, nongovernmental, and public-assistance programs to provide housing and to promote restoration; long-term care and treatment of affected persons; additional measures for social, political, environmental, and economic restoration; evaluation of the incident to identify lessons learned; post incident reporting; and development of initiatives to mitigate the effects of future incidents

7.2.2. Phases of sheltering

In the case of sheltering, the phases can be represented more specifically.

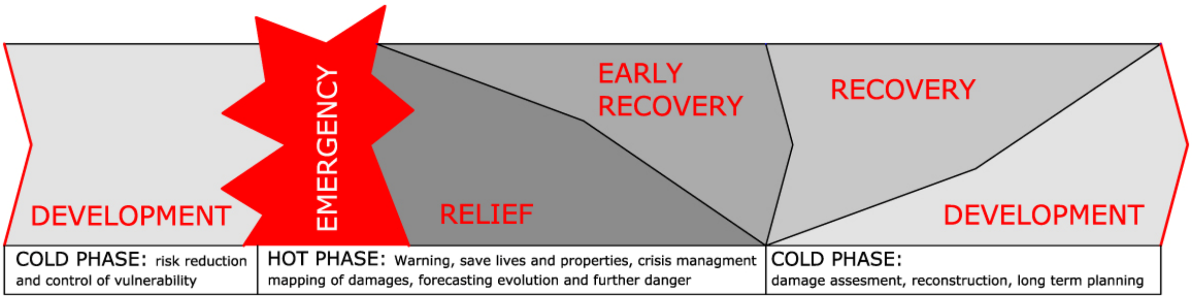


FIGURE 7.3: THE PHASES OF SHELTERING

In the case of sheltering, an *emergency* can be considered a specific phase which starts as soon as the disaster strikes. It is dedicated to saving lives. After the emergency, the *relief* phase comes which deals with the main activity of keeping people alive, curing the injured and sheltering them from sun and rain to keep them dry and warm. Later, the *early recovery* starts. In this phase the organization tries to let people be independent. After that, comes the *recovery* phase, a period in which the community becomes independent and the relief phase is totally over. In parallel, and according to the location, the *development* phase may start, characterized by a permanent helping in the direction of a stable situation.

EMERGENCY MANAGEMENT AND SHELTERING: PHASES

To compare emergency management with the sheltering phases we can state that the response phase is the combination of emergency, relief and early recovery.. Recovery can be compared with the emergency management definition while development includes mitigation, prevention and preparedness from the sheltering point of view.

7.3. Temporality of the emergency: two scenarios

Sheltering sets its basis on the idea that emergency is a period limited in time in which a new temporary settlement composed of houses, shops, schools and hospitals is set up while the old one is being rebuilt or repaired.

THE "PINHEIRO PRINCIPLES"

This process of displacing people, from their old life to a new artificial one brings along new risks and variables to take into account. The principles and guidelines to deal with DP (Displaced Population) and to set up THS (Transitional Human Settlements) are clearly summarized in the "Pinheiro principles"[5].

Psychological analysis has shown how delicate this temporary phase can be, especially in poor countries where paradoxes may arise[6]. People react differently and in different ways

[5] COHRE – Centre on Housing Rights and Evictions (2006), *The Pinheiro principles: United Nations principles on housing and property restitution for refugees and displaced persons*, COHRE, Geneva.

[6] Chalinder, A. (1998) *Temporary human settlement planning for displaced populations in emergencies* ODI, London.

to an emergency situation, therefore sheltering needs to take into consideration aspects which may not be straightforward or predictable. The best example in relation to the concept of temporality is related to the strength of ownership of the new, temporary solution. On the one hand, especially in developed countries, victims look forward to coming back as soon as possible to their homes and properties, but in some other cases, especially in third world countries, it can happen that temporary solutions may turn into a valid alternative to the previous property.

TRANSITIONAL VS PROGRESSIVE APPROACH

Ownership of land becomes an issue in these cases, as happened in Haiti recently[7]. For this reason the transitional approach may turn in social stress and therefore, when people are not displaced, a "progressive" approach which tries to keep people close to their belonging and put them in a condition to restore or repair their dwelling might be an interesting alternative to THS.

7.3.1. Temporary architecture: specific features

Traditional static architecture is not able to address needs which arise either in the transitional or progressive scenarios. On the other hand, technologies, materials and building methods explored in temporary architectures, such as exhibition pavilions or sports infrastructures, may be inspiring examples and offer those features which are crucial for the success of the sheltering programme.

FIG. 7.4: THE FLOATING HELIUM-FILLED ROOF OF THE SERPENTINE GALLERY, OMA 2006

Temporary architecture perfectly fits the problems of temporality typical of the sheltering phases. It refuses monumentality, it is essential, efficient, and fast, it avoids unnecessary elements, it is easily adaptable. Temporary architecture is designed to be set up in one place for a limited period of time and then to be easily dismantled: the absence of or limited foundations, lightness of components and dry assembly are specific features.

FIG. 7.5: CAVALIA CIRCUS BY CANOBBIO, 2003

The idea of shifting from a monumental and static architecture to a temporary one is not new and, over the last twenty years, it has grown together with rising awareness of sustainability and protection of the environment.

Technologies of this kind derive from the shelter of nomadic tribes of the past but also for special structures like circuses or other tented structures, in use at the present time. Problems of transportability (limitation in size and weight) and durability of the materials and connections are the main limitations in the design of temporary structures.

FIG. 7.6: IMPROVISED DISTRIBUTION SYSTEM, KENYA

If, centuries ago, structures were transported by animals and erected by men, nowadays airships or trucks can easily move much larger structures that can later be assembled using machines: thus larger temporary structures are now available. In an emergency, on the other hand, improvised transportation means are still very common and construction cannot rely on the availability of machinery, therefore, other solutions need to be taken into consideration.

FIG. 7.7: STAGE FOR THE KONGSBERG JAZZ FESTIVAL, 2006

Circuses, showrooms and pavilions are modern temporary shelters: an incredible variety of materials can be used in temporary architecture and several building systems have been

[7] ALNAP, Rencoret N. et al., (2010 b), *Haiti Earthquake Response, Context analysis,* London.

developed to produce a long series of astonishing examples. From the durability point of view, stronger materials and smart construction systems have been developed: the faster and easier the structure can be set up, the better it is.

Temporary pavilions give input about the definition of a robust and efficient system which can be shipped, built and dismantled several times. On the other hand, these examples rarely imply people staying for long periods as would happen in an emergency shelter, therefore specific adaptation and investigations into internal comfort is required.

7.4. Designing according to expected lifespan

As already mentioned in Chapter 2, architecture for emergency is based on different principles and sustainability is definitely one of these. Emergency sheltering is the most clear example of architecture which has to be designed for a specific lifetime. Constraints of transportation, cost and performances make this issue particularly relevant as extensively investigated by research into so-called “four dimensional design”[8].

RATIO COST / BENEFITS

In an emergency, the cost/benefits ratio is probably the first variable used to identify the best sheltering solutions. Expected life spans largely influence this variable and therefore it needs to be analyzed closely.

First off, the lifespan should not be considered only when the solutions are deployed. Expected lifespan when products are stockpiled is also crucial. In fact, it may be that solutions are stored for 3-4 or even more years in warehouses around the world, usually close to the “hot spots” of the planets where disasters are more frequent. In these warehouses, protection from sunlight is not assured and temperature and moisture levels may be prohibitive. Expected lifespan is, therefore related both to structural properties like material strength or flexibility of parts, but also healthy parameters such as bacteria and fungi prevention.

LIFE SPAN OF THE PRODUCT AS A WHOLE

Once deployed, the life-span of the sheltering product depends on the durability of each subcomponent or element included in the shelter itself. It may happen, for example, that canvas will last two years on site but connection belts or anchor point may deteriorate much faster. If these components cannot be replaced or substituted, the whole product must be thrown away with a consequence loss of money and components still in good condition.

In contrast, from the manufacturing point of view, there is no reason to use components which last much longer than the canvas (which range from less than one year for tarpaulin to five for polycotton canvas) because this would turn into a higher cost without any improvements in performance.

---

[8] Henrotay C., Debacker W. , Mollaert M., De Wilde W.P and Hendrickx H. (2006), *Four dimensional design: a strategy for efficient shelter and sustainable housing after conflict-based and natural disasters* Proc. of 1st Conf. on Ravage of the Planet, Management of Natural Resources, Sustainable Development and Ecological Hazards, eds. Brebbia C.A., Conti M.E., Tiezzi E., 341-350 Wessex Institute of Technology, UK.

REUSE AS ADDITIONAL VALUE

In addition, a deep analysis of the lifespan of the materials distributed must include second or third uses which are common, especially when resources are scarce. Everything that can be reused for other proposes has an additional value. Packaging devices, for example, are often thrown away with a consequent problem of trash treatment or pollution. Reuse must be balanced against the level of performance and safety too. Reuse of worn-out materials may create problems relating to health or stability of the structure. To prevent the incorrect use/reuse of distributed materials, a list of second/third uses must be selected together with best practices and then communicated to final users, so as to support them and avoid unexpected risks.

RECYCLING

Last but not least, an effective solution should take into consideration its impact from a general point of view. Especially in large disasters, due to the greater amount of materials deployed, one should take into consideration the whole life cycle of everything distributed and, therefore the recycling must be considering too.

In fact, if a natural disaster damages old settlements then during the transitional phase manmade disasters are created too, due to haste and/or lack of planning. Soil or water pollution are only two examples of these risks which might be reduced by the application of recyclable or natural material that can be integrated and processed by the affected community. Mono-material or natural components are certainly more competitive, in this direction.

7.5. Speed and seed approach

The “Speed & Seed” approach arises from discussion of the European project S(p)eedkits[9] and involves a combination of rapid and easy to assemble solutions which, due to their intrinsic values in terms of function and material, are the first seed of the development of the communities or families affected by the disaster. This approach perfectly integrates the design based on lifespan presented in the previous paragraphs but goes even further. It combines a speedy solution with the possibility of distributing specific kits at the right moment during the emergency, recovery and development phases.

According to this principle, different materials with different expected life spans are distributed at different stage of the emergency. Variables that influence the distribution vary from the availability of resources (from NGOs or local authorities), the possibility of including resources available on site, the culture, the magnitude of the disaster, and so on. The majority of materials and components are carefully selected to offer their services according to the needs at the time of deployment but also to give their contribution in a second or third stage. Structural elements, for example, can be the poles of the primary roof but can be reused in a later stage as beams or columns for a permanent dwelling. At the

[9] www.speedkits.eu

same time, the flysheet used for shade in the first repair, can be used as an insulating sheet for the floor during the development phase.

The innovative aspect of the approach is not to rely on reuse of material, a practice already in use in different sectors and ways. On the contrary, the real innovation comes from the strict link between delivery of components (e.g. kits) and the stage they are deployed. Every stage is the result of a trade-off between the variables listed above and, therefore, help can be calibrated according to the evolution of the emergency and the results achieved thanks to the previous deployment. A continuous and progressive implementation of the solution is checked and pushed when needed and when conditions are ready. These systems, for this reason, stimulate the bottom up approach to development.

This approach can be seen as an evolution of the transitional settlement one, or at least an integration of it, especially in all those cases when people are not displaced but still require the support of a sheltering programme to come back faster to a normal life. In this respect, the kind of investment is comparable to the one of the Transitional approach as shown in picture 7.8 and consists of an incremental process.

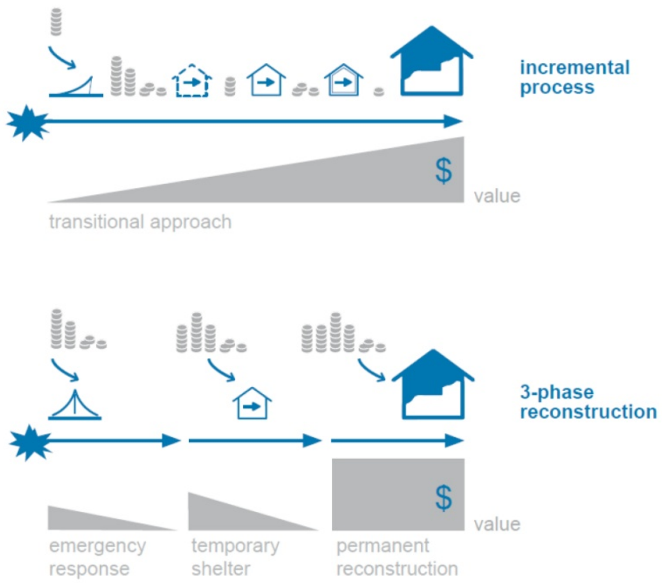


FIG. 7.8: DIFFERENT INVESTMENTS: INCREMENTAL PROCESS VS MULTIPLE PHASE RECONSTRUCTION

FIG. 7.9-10-11: TWO STOREYS SHELTER ÜBERSHELTER, PORT-AU-PRINCE, HAITI 2011

7.6. Transitional settlement approach

"Transitional settlement approach" is an important innovation, shifting the common conception of shelter from an object (such as a tent) to an overall process and thereby bringing real improvements in how humanitarian agencies approach and implement shelter programming.

The transitional settlement approach has been developed and defined through a peer-review process initiated by the "Shelter Project", over the last ten years. The basic literature on the topic starts from the extensive research into the topic from 2005[10] and ends up with the transitional shelter guidelines[11] of 2011. The approach calls for agencies to look beyond their traditional, limited focus on the provision of tents and camps. It emphasizes the need for a transition to durable settlement solutions and local development.

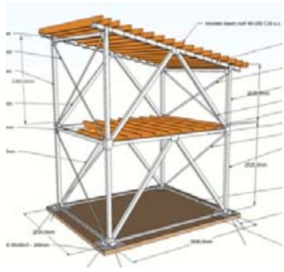


Fig. 7.12: Two storey shelter for Haiti developed by Tu/e

Ten principles have been identified by the Shelter Centre which can be found in the literature[12]. Out of them, number 9 says: “transitional shelter is an incremental process of sheltering which should start with the first distribution of relief items and continue until durable solutions have been achieved”. Within this framework, transitional shelters can be defined as shelters “which provide a habitable covered living space and a secure, healthy living environment, with privacy and dignity, to those within it, during the period between a conflict or natural disaster and the achievement of a durable shelter solution”[13].

Fig. 7.13-14-15: Examples of transitional shelters in Pakistan (timber frame) Indonesia and Vietnam (steel frame)

The Transitional Shelter Prototypes project[14] has begun to produce its first results, in the form of prototypes tested in the field by several agencies. Results are from a large variety of materials (e.g. metal or wooden frames), layouts (one or multiple storeys) performance and costs.

In parallel, manufacturers and tent producers have developed specific products in this direction These shelters are designed to meet the Transitional Shelter Standards which have been set in accordance with humanitarian practitioners who have experience in delivering emergency shelters suitable for stockpiling, and ready for quick dispatch in the event of an emergency.

The Transitional shelter approach arises from the compromise between different variables. Safety, lifespan, size, comfort, privacy all have to face the limits set by cost, lack of time, number of shelters to be built, materials available, maintenance and upgrade possibilities, equity, capacity and construction skills. Compared to the standard sheltering approach, where the final solution is deployed all in one, the transitional approach starts from the minimum habitat but foresees further steps of implementation.

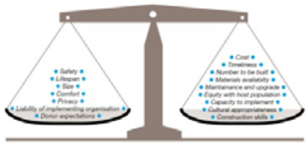


Fig. 7.16: The compromise of transitional settlement approach

A transitional shelter approach was used during the Indonesian tsunami response of 2004. This experience suggests that, if there is a wider understanding of the settlement options selected by the entire affected population, and these are appropriate, then they are supported, “additional opportunities emerge for coordinating the transition from shelter to housing”. The use of transitional settlements enables agencies to take a holistic approach to providing shelter assistance for those displaced by conflict and disaster. It can support both communities and infrastructure, cutting across other sectors such as water and education, and taking a broad livelihood-focused approach.

Fig. 7.17: TransHome by NRS International Group

---

[10] Corsellis, T. and Vitale, A. (2005), *Transitional settlement: displaced populations*. Oxfam, Oxford

[11] Shelter centre, (2011), *Transitional shelter guidelines*, Geneva

[12] Shelter centre, (2011), *Transitional shelter guidelines*, Geneva

[13] Corsellis, T. and Vitale, A. (2005), *Transitional settlement: displaced populations*. Oxfam, Oxford

[14] The process has been carried out by the Shelter Centre and, together with the definition of guidelines, prototypes have been build and analyzed too. Six deigns of transitional shelters developed by companies are described and compared in Shelter Centre (2009), *Transitional shelters prototypes* while additional eight designs developed in the field are listed in IFRC (2011 a) *Transitional shelter - Eight designs*

The transitional shelter approach offers a new paradigm and position for sheltering work, which in theory changes the processes involved and helps to shift agencies away from a short-term product focus. However, at the time of writing, the approach is still somewhat contested, with much confusion about terminology and meaning.

Transitional shelter principles derive from the 70s, and the approach developed in 2002-2005 still has its detractors. The main doubts derive from the fact that the solution has to rely on local industry to find the right materials and components to be applied in subsequent stages. For this reason a series of solutions have been designed by private companies like the TransHome by NRS international.

FIG. 7.18: TS200 TRANSITIONAL SHELTER DEVELOPED BY LOSBERGER

Another well known example is the TS2000 developed by Losberger. For twice the cost of a traditional family tent, the TS200 Transitional Shelter aims to be a temporary house based on a re-useable and durable aluminum frame (a versatile L shaped profile) which bridges the period between emergency sheltering and the rebuilding of permanent housing, without having to rely on the availability of local construction materials[15] or at least, offering the essential components to set up a basic shelter which might be implemented in a later stage.

7.7. A new approach: progressive

An evolution of the concept of transitional shelter is here foreseen by the author as a process based on the distribution of simple elements which can be progressively implemented or substituted by locals. As clearly presented in picture 7.19, the progressive process follows the transitional reconstruction for non-displaced populations.

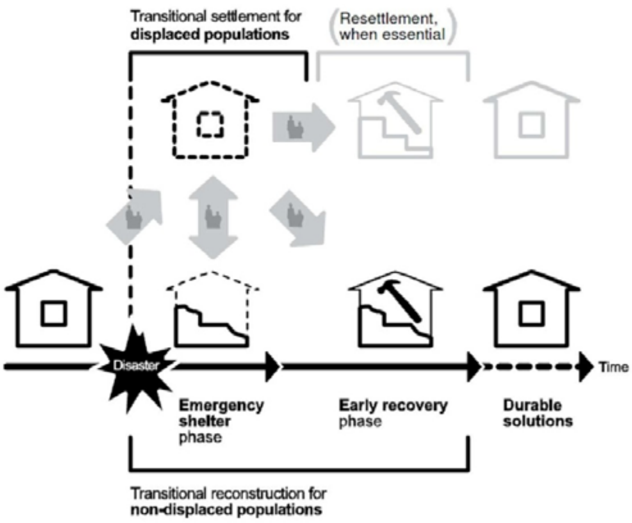


FIG. 7.19: THE TRANSITIONAL SETTLEMENT APPROACH

[15] www.transitionalshelter.org

If on the one hand, transitional shelters for displaced population at a certain moment, are to be abandoned, the progressive system is based on the idea that the very first emergency shelter should be the starting point of the final dwelling or, on the other hand, should offer subsystems that can be installed autonomously as a temporary shelter or combined with existing dwellings to reinforce or repair them temporarily while waiting for the final intervention to come.

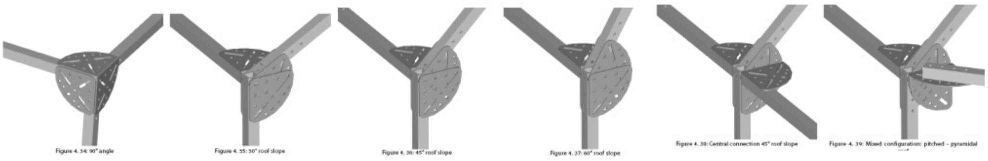


FIG. 7.20: L-SHAPED CONNECTION PLATE FOR ADAPTABLE, VERSATILE AND COMPATIBLE SYSTEM

FIG. 7.21: THE EMERGENCY HOUSING PROJECT

Starting from this assumption, Part Two of this dissertation will focus on the development of a progressive sheltering strategy able to link the rapid deployable solution of the very first hours with the final dwelling. Learning from studies of components such as the adaptable connection plate for framed shelters, the progressive system aims to join together the idea of continuous implementation of the solution together with the concept of adaptability, already mentioned in Chapter four of this dissertation.

8 CONCLUSIONS

The excursus of the first seven chapters analyzed the problem of sheltering from different points of view with the aim of clearly identifying a path that researchers, operators in the sector and industry could follow to came up with true innovation in the field, which actually is looking constantly for better solutions even if it seems locked and static.

COLLABORATIVE PROCESS AS DRIVER OF INNOVATION

Is innovation really needed and why are the solutions applied still the same despite the development of technologies and materials being fast while the humanitarian response still fails?

These kinds of doubts were discussed in Chapter one, where it clearly emerges that the humanitarian sector is probably still reluctant as regards radical innovation, however, thanks to collaborative approaches, innovation *is* gaining a much more relevant role in the humanitarian sector too.

The problem of leading the process of innovation together with the crucial role of research centres as collector of inputs from the field and from the industries has been discussed too. In addition, it has been clearly identified how the ultimate goal of innovation in the sector is to improve victims' conditions, therefore good innovations need to constantly keep that in mind.

UNDERSTANDING THE COMPLEXITY

The complexity of the sheltering process has been approached trying to highlight contrast among the continuous debates within the humanitarian sector. Out of a large number of "hot topics", six have been identified and presented from the author's point of view.

From Chapter 2 to Chapter 7, the thesis focused on specific aspects of these complex scenarios, highlighting the leverages on which a successful innovation should focus and identifying the most promising strategies to pursue to improve humanitarian response.

This research occupies two thirds of the whole dissertation but it has a strategic value. In fact, it is well know that a lot of research into and development of sheltering has been done (and is ongoing) in the last years but the majority of these results have not been applied and will remain on paper. The reason comes from a wrong approach to the matter which rapidly looks for solutions instead of focusing on understanding the problems. This should be done for every research but in the case of application in emergency it is even more true.

PROCESS AND PRODUCTS

This is the reason why in Chapter two, it has been clearly demonstrated that sheltering should be considered as product and process at the same time and each emergency is unique. Standard solutions (products) or pre-defined methods (processes) cannot be an answer to the complex process of emergency. Needs changes fast, therefore, solutions must be able to adapt to them rapidly. In this way it will be possible to go beyond mapping and lists of requirements which, most of the time, do not represent the reality and cannot be identified in advanced. Textile technology is promising in this respect: intrinsic properties of lightness and efficiency, together with wide acceptance and handling capabilities all over the world, make this technology the perfect starting point for future innovations.

MATERIALS AND PERFORMANCES

This is the reason why Chapter three focused on the importance of the materials and its performance. Properties of lightness and efficiency together with simplicity in use are crucial to answer victims' needs. Lightness in materials can be purchased in different ways but lightweight design goes beyond kg/m^2. A combination of lightness and simplicity turns out to offer the best service in these kinds of application.

OPEN DESIGN AND OPEN SHELTERING

Modularity and adaptability have been investigated in Chapter four, finding the answer in the "openness" of the design process and of the final product too. Adaptability brings the focus on the final users while modularity offers clear advantages in the design and planning phases.

IMPLEMENTABLE SYSTEM

Among ready to use systems, "all in one" and "component based" strategies have been compared in Chapter five: results show clearly that the rapidity of deployment is useless if the solution is not able to take into account the context and the needs which in an emergency situation are constantly in evolution. This is why a kit strategy, based on implementable systems has been identified as the most promising to pursue with clear advantages in terms of impact in medium or long term, for example, on the local economy.

HIGH-TECH IDEAS AND LOW-TECH APPLICATIONS

In Chapter six, the analysis tried to go beyond the contrast between low- and high-tech systems which does not make any sense without considering a specific contest and community. Examples of different approaches to solve the same problems showed how high-tech ideas can be put into practice with low-tech materials or technologies too and that every contest has its own specificity: the success of the solutions passes through the smart uses of resources available on site. From these considerations the Tensairity® principle emerged as being able to combine in a smart way air and rigid elements in a system that can be implemented over time, when required and by the final users.

PROGRESSIVE SYSTEM

"BOTTOM-UP" STRATEGY

The importance of timing in emergency concludes the analysis: according to the emergency phases, different solutions may be deployed. Time and emergency are combined in a "progressive" way which is in contrast with the fixed and static nature of the product from the shelf but it also represents an alternative to the transitional settlement approach: a "progressive" approach includes the concept of adaptability and is a process which arises "bottom-up" while transitional, most of the time, remains "top-down".

As a conclusion, it emerged clearly how “simplicity” is the concept that links all the topics presented in this dissertation till now. Simplicity implies the use of a few elements, materials and connectors without any redundant parts: less material (in terms of number and mass) means effectiveness of the solution, velocity in the mounting phase, lightness in the transportation and easiness in handling by any actors at any stages of the emergency. Simplicity is also at the basis of the structural concepts of tensile structures and gives its best when standard and widespread materials can be included in the system too.

SIMPLICITY

TEXTILE ARCHITECTURE

Textiles are materials of this kind, which can be easily processed in several different ways almost all over the world, especially in poor countries with economies based on labour intensive activities.

TEXTILE SECTOR

As a consequence, a combination of standard materials with the simplicity of the innovative principle, has led the author to think that Tensairity® might have the potential to “fill the gap” combining the advantages of inflatable with the durability of local elements toward the transitional and development phase. Anyway, the theoretical principle requires a process of simplification to became real practice, trying to keep the “high-tech concept” but turning it into a “low-tech” way of applications. This objective will be one of the goals of the second part.

TENSAIRITY® PRINCIPLE

P2

PART II: DESIGN OF A RAPIDLY DEPLOYABLE INFLATABLE PROGRESSIVE SYSTEM FOR IMMEDIATE RESPONSE

1 INTRODUCTION

Rapidly deployable sheltering systems for military purposes have been investigated extensively for a long time by the industrial sector. Experiments by Bird Air made inflatable technology famous all over the world. In parallel, systems that can be assembled in few minutes by a limited number of people without any particular skills have long attracted the interest of the humanitarian sectors and operators involved in the field. Humanitarian aid is, first of all, a life-saving activity in which any waste of time can cost lives. An effective solution in this direction would definitely be helpful and hugely appreciated by all concerned.

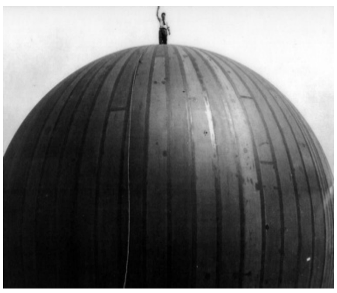


Fig. 1.1: Walter Bird on top of one of his famous "Radomes"

Unfortunately, the development of such a kind of structure is not as easy as it sounds and has to take into consideration all the factors already addressed in the previous sections of this dissertation, which might be in contrast with such a universal solution. As extensively highlighted in the first part, effective sheltering is based on the adaptation of features to a specific location in order to match the culture, habits and material technologies of the area of the intervention. In this way, humanitarian aid can offer shelter and, at the same time, stimulate the local economy and strengthen the resilience of a community that needs to be able to pursue future development without external help (see Chapters 6 and 7).

Universal vs specific solutions

Rapidly deployable systems indicate a particular category of product that may include different technologies but combines two basic characteristics. On the one hand, rapidly deployable systems are characterized by speediness in terms of transportation which comes from imposing strict boundary conditions: the total weight of the system together with the weight of the single components is limited and, at the same time, the total volume of the system when packed is also reduced. On the other hand, these systems need to be designed in a way that makes them easy and fast to assemble and dismantle, in case of necessity. Working on these two aspects, transportation and assembly, this kind of system is designed to reach even the remotest of places where there is an emergency and be deployed in a matter of minutes with the help of a limited number of people.

Speed in terms of transportation and assembling

MILITARY

FIG. 1.2: MILITARY DOME TENT FOR PROTECTION

FIG. 1.3: INFLATABLE TENT FOR CAMPING

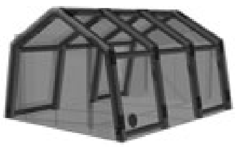


FIG. 1.4: SELF DEPLOYABLE INFLATABLE TENT FOR RAPID RESCUE

FIG. 1.5: CONTAINER HOSPITAL

Several rapidly deployable systems are currently available on the market and a few of these are also used in the humanitarian process of relief. The military sector is the largest developer of these kinds of product. A large span hangar, together with a command centre and warehouses are just some examples of applications which employ these kinds of structure.

Military structures are usually rapid to use in terms of dimension and technology while lightness is, most of the time, a secondary consideration due to the ready availability of workforces and on-site machinery.

Structures for leisure activities, on the contrary, such as camping, fashion or sports events make their contribution when they are smaller; these systems have to fit the size of bags or backpacks and lightness becomes the main issue for the success of the solution. Some good examples come from the world of hiking and trekking where complete insulated wind- and water-proof devices can be packed into a volume of few litres.

Some ready-to-use systems can be considered rapidly deployable too, but not all of them fulfill the requirements of fast transportation and delivery. The container solution, for example, is sometimes too large to fulfill the conditions of a solution that is easily transportable in a matter of a few hours, which may also be impossible in the case of remote areas. Pallet- and bag-level means of transport (or at least the possibility to split the shipment into smaller parts) are usually the crucial advantage of this kind of solution.

For several years now, the emergency field has been using rapidly deployable systems such as inflatable shelters with small (5m) and medium spans (7-8m) or rapidly deployable emergency hospitals the size of a caravan or container which are in use by some NGOs. Further examples and information can be found in the Red Cross emergency items catalogue[1] but also by surfing the Web. Unfortunately, some of the fancy solutions available on the net will never be applied in the field as they claim more than they can actually deliver. Simple solutions, conversely, have been widely adopted with success and efficient results.

GENERAL GOAL

The importance of the very first hours and days after an emergency has struck clearly pints up the limits of the current sheltering approach and technologies based on “all in one” solutions, which tend not to look beyond the first days towards the development phase, in fact may sometimes slow this process down. A mix between an effective solution for the very first hours with a sheltering system that lasts into the development phase is the ultimate goal of this research.

AIM OF THIS SECTION

The aim of the next chapters will be to illustrate the process carried out to develop a lightweight system which tries to combines the advantages of a rapidly deployable solution with the principle of the “progressive shelter” already mentioned in Chapter 7 and in the conclusions of the first part. The background studied in Part One is the starting point for the product development of this innovative shelter system. The results presented in the following chapters take into consideration the process of innovation in the humanitarian sector (see Chapter 1) and starts by a careful targeting of the needs and an identification of

[1] procurement.ifrc.org/catalogue

the solution (see Chapter 2). Characteristics of lightness, simplicity (see Chapter 3) adaptability (see Chapter 4) are mixed in a component-based approach (see Chapter 5) which combines the advantages of high-tech concepts with low tech materials and manufacturing processes (see Chapter 6). Ready-to-use characteristics are counterbalanced by an implementable/progressive approach which prioritize the time factor (see Chapter 7).

Inflatable technology, and in particular the Tensairity® principle, has been selected as a promising construction system for several reasons that will be presented in the next chapters. Analysis of the state-of-the-art shows that current inflatable solutions present several disadvantages in their application in emergency: first of all, cost is definitely prohibitive in the case of large disasters, especially in third world countries. Maintenance is the highest cost which can be reduced by a design that allows the replacement of single components. Moreover, from a structural point of view, low pressure arches suffer large deformations due to variations in air pressure which are temperature dependent. In addition, inflatable are always included in "all-in-one" solutions which are "closed" and do not allow modification either by end users or practitioners.

LIMITS OF THE CURRENT SOLUTIONS

The principle of Tensairity® behaves differently and could bring new life to inflatable technology and let its light shine. Let's indulge in a brief excursion to learn the specific features of this principle before continuing.

The Tensairity® principle

The development of a new inflatable system based on the progressive concept is described in the following paragraphs. The Tensairity® principle has been identified as the vehicle that could provide an effective answer to specific requirements all in one.

As clearly described in the literature, a "Tensairity® beam consists of a simple air beam and a compression element which is connected by two cables running in helical form around the air beam. The cables are connected to the end of the compression element. Thanks to this connection, the cable force is transferred to the compression element, acting here as a compressive force P. […] The key principle of Tensairity® is to use low pressure air in an attempt to prevent compression elements from buckling"[2].

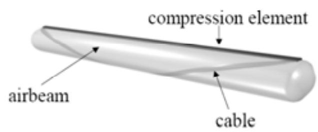


FIG. 1.6: TENSAIRITY® BASIC CONFIGURATION

In reality, the compression element is prone to buckling, however, in general, the buckling load is much smaller than the yield load which means an inefficient use of the material and extra weight for the compression element. In Tensairity®, the air tube plays a key role. The compression element is tightly connected to the membrane of the air beam, and as result is continuously supported by it. In fact, the membrane acts as a continuous elastic support for the compression element. The rigidity of this support is determined by the membrane stress, which itself is proportional to the overpressure inside the membrane tube. Different cases of a compressed element prone to buckling in trusses and in Tensairity® systems are shown in figure 1.6.

[2] This passage and the following description of the principle of Tensairity® is mainly taken from Luchsinger et al., (2004)

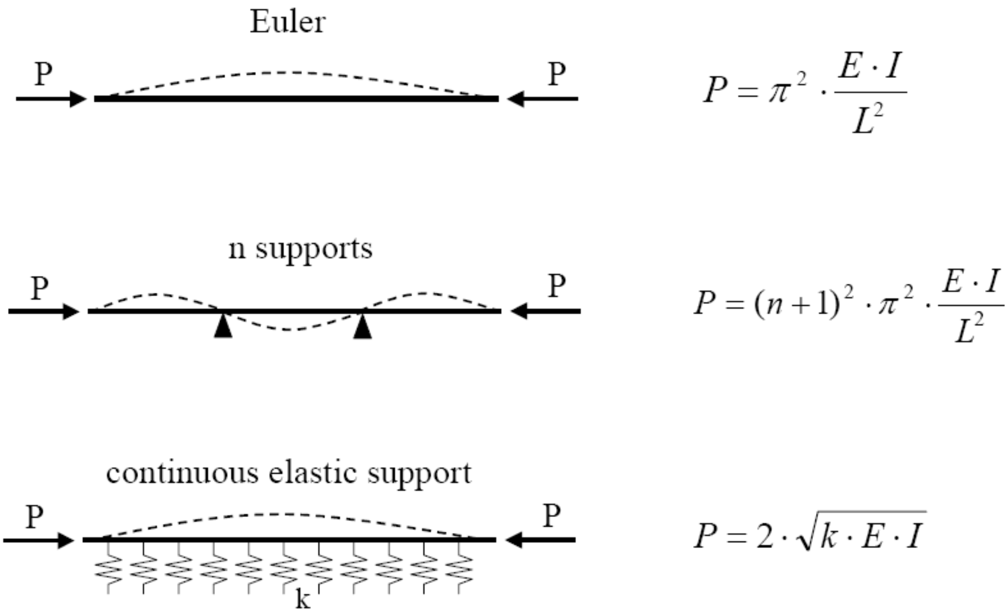


FIG. 1.7: BUCKLING BEHAVIOUR OF SLENDER ELEMENTS UNDER COMPRESSION LOAD

A structural analogy is very helpful to understand Tensairity®. The analogy to a truss is shown in figure 1.7. The Tensairity® girder has an upper compression element and a lower tension element. Both these elements can be found in the truss with the same functionality.

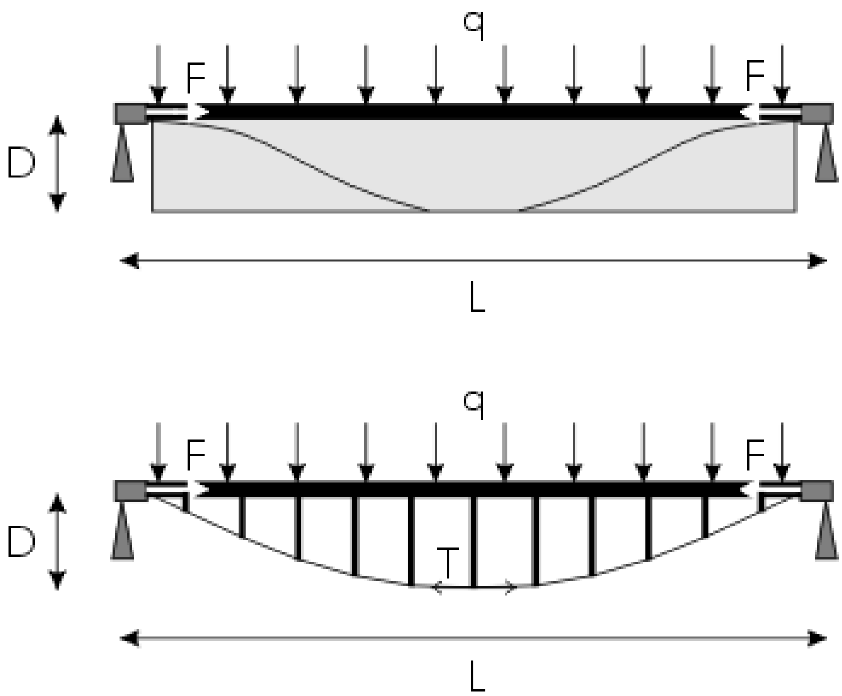


FIG. 1.8: COMPARISON BETWEEN A TENSAIRITY® BEAM AND A TRUSS

Assuming a parabolic shape of the tension element and compression element in the truss model, half the homogeneous load needs to be transferred to the tension element by the vertical struts, while the force in the diagonal struts vanishes. In Tensairity®, the vertical and diagonal struts are missing. Thus this transfer has to be fulfilled by the fabric and the compressed air.

An interesting feature of Tensairity® and other pneumatic structures, is that the compressive forces are transmitted by fabrics under tension. Obviously, this transfer depends on the pressure and thus a relationship between load and pressure can be established. As for the cylinder, the pressure is proportional to the load per area and independent of the length or slenderness of the beam. Consequently, for a given snow load, for example, the necessary pressure in the Tensairity® girder is the same for a small roof as for the covering of a huge stadium. This is an interesting property of Tensairity® and is especially important in wide span applications.

2 DESIGN GOALS

BRIDGE FIRST EMERGENCY WITH DEVELOPMENT

The goal of combining the sheltering phase of the very first hours after an emergency has struck with the transitional and development phase, has not yet been achieved with current sheltering methods. In this respect, the distribution of plastic sheeting is fast and effective but to come up with a decent shelter using two 4x6m tarpaulins is no easy matter.

A STRUCTURAL KIT

On the other hand, transitional settlement strategies need more time. To shorten the gap between those two phases, a structural kit which uses plastic sheeting but can also be used in other ways, for example to reinforce or repair damaged dwellings, is the ultimate goal of the experiments and tests of the following chapters.

The focus on the development of an innovative, rapidly deployable implementable structural system has three major goals which cover the methodological, structural/architectural and technological points of view.

METHODOLOGICAL GOALS

From a methodological point of view, the following case study aims to apply the innovation strategy highlighted in Part One. The progressive approach has been applied to try to overcome the impasse in the innovation process within the humanitarian sector. The system is studied to offer two different services, the first related to product, the second to process.

PRODUCT

On one hand, this can be considered a fully integrated "ready-to-use" system, in which the design is standard and the set-up is "plug-and-play". The results of this approach can be useful for the fast setting up of operating theatres, hospitals, community shelters, meeting and collective centres and every other occasion that requires immediate shelter for the first hours after a disaster has passed.

PROCESS

On the other hand, the design is considered as an implementable system where structural components can be added when needed and if resources are available, and the whole system can be used alone or aggregated in a modular way, sheltering whatever is necessary at the moment of the emergency.

The adaptability of the configuration is therefore crucial, and tries to be as usable as possible and to fit specific cases. The system is also designed to be either fully autonomous or, in the event of available local materials, to make use of whatever can be found on site to improve its structural performance. The element is therefore seen as something more than a single product but something which can serve the sheltering process in a more flexible and adaptive way; i.e. a combination of the ready-to-use and implementable approaches presented in Chapter 6.

READY TO USE + IMPLEMENTABLE = PROGRESSIVE

STRUCTURAL / ARCHITECTURAL GOALS

From an engineering point of view, the research aims to surpass the existing performance of lightweight constructions through investigation of a reinforced inflatable system that can resist higher loads and/or allow the application of slender sections instead of the traditional thick and heavy air beams of the state-of-the-art, keeping the inner pressure low.

As mentioned above, the load-bearing capacity of inflated structures is limited and thus the range of applications is restricted. The problem of the limited load-bearing capacity of inflated structures has been overcome by Tensairity®[1], a new technology by Airlight[2] developed in collaboration with Prospective concepts[3]. The combination of compressed air, fabrics, struts and cables in Tensairity® is new in structural engineering and can offer interesting opportunities when time and transportation are crucial.

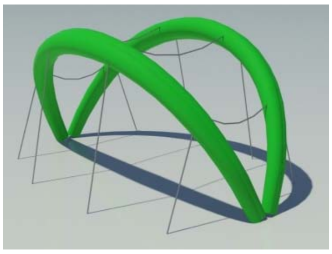


FIG. 2.1: TWO-ARKS CONFIGURATION

From an architectural perspective, the system has been designed from the end-user's point of view trying to offer support which goes beyond shading from the sun and protection from rain. A decorous dwelling, able to guarantee safety, protection and dignity as presented in the definition of sheltering[4] in humanitarian action, is the ultimate goal. Smart and efficient solutions from the usability and flexibility points of view, dedicated to the world of sports (hiking and camping) or media (exhibition or events) are considered useful references to plug the gap between these solutions and current ones.

TECHNOLOGICAL GOALS

The structural elements are designed as an implementable system which can be set up quickly and offer different performance levels according to the number of components available at a specific phase of the emergency. The actual manufacturing of the inflatable, its connection with the rigid struts, foundations and transpiration system are analyzed from the technological point of view.

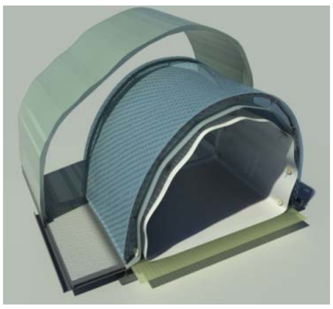


FIG. 2.2: MULTI-LAYER SYSTEM

Air comfort inside thin films or textile finishing is a further open problem which has not yet been solved. Tolerable air temperature and humidity control in enclosed spaces is something difficult to achieve, especially in harsh conditions such as tropical or desert areas. The main limitations arise from the intrinsic characteristics of the lightweight materials used: thin layers have no mass and therefore inertia is almost negligible. A technology based on a multilayer system is, therefore, the main strategy to control interior comfort.

---

1 Luchsinger R.H. et al., (2004), *The new structural concept Tensairity: Basic Principles*, in Progress in Structural Engineering, Mechanics and Computation, ed A. Zingoni, A.A. Balkema Publishers, London.

2 www.airlight.biz

3 www.prospective-concepts.ch

4 See appendix 1

The possibility to change and select the most appropriate layers just like humans do when changing clothes according to the seasons, is a promising analogy which can offer interesting advantages to the shelter's guests. Flexibility in shaping the interior volume is a further option to ensure privacy and increase social acceptance of the solution.

The design of technological components to turn this concept into reality is not part of this research, however the structural component will take into account the necessity to connect together a multi-layer system which is the only way to ensure a certain degree of thermal comfort.

FIG 2.3: HABITAT CUSTOMIZATION, CONCEPT FOR A HIGH COMFORT CAMPING TENT

The ultimate goal is to come up with the design of an implementable structural component that is innovative both as a product in itself and is able to have a strong impact on the sheltering process it affords. Consideration of sheltering as a process instead of a simple product is the starting point of this investigation which aims to bridge theory and practice by focusing on a specific case.

BENEFICIARIES

The results of this research are intended for two beneficiaries. First of all, all the practitioners who might use it as a ready-to-use, lightweight and robust mid span shelter, that can host NGO operators involved in rescue phases. Secondly, the direct victims who can use it as a flexible structural component to be combined with local materials and/or other available technologies to suit specific contexts and their needs. The inspiring examples selected from the world of lightweight structures presented in Part One are the background to the pursuit of true innovation.

3 CONCEPT, DESIGN AND BLUEPRINTS

3.1. Preliminary studies and background

LIGHTWEIGHT STRUCTURES

Lightweight structures are designed differently from standard buildings for several reasons. First of all, the materials involved are at the cutting edge of the sector: the combination of textiles or film materials, fibre-reinforced composites and dry-assembled elements requires precision both in the design and construction phases that are closer to industrial production methods rather than those that characterize the building construction sector (see Part I, Chapter 2). Moreover, knowhow about the behaviour of such materials is not widespread and therefore, only a few players have the capacity to manage these kinds of projects.

AIR: CONSTRUCTION MATERIAL

Architects, engineers and designers have already faced the problem of equilibrium in combining materials characterized by different stiffness, stretching, and deformation under external agents.

In the special case of designing inflatable structures, the above-mentioned elements are combined with air which literally becomes a "construction material", a flexible "brick". The compressive forces of the air counterbalance tensioning forces on the surface membrane. Flexible and deformable materials coexist in an equilibrium which is dynamic and reacts actively to boundary conditions such as external loads but also environmental temperature. For all these reasons, inflatables are considered "live" mutable structures, in direct contrast with standard "static" building construction systems. These characteristics are clearly shown in Anish Kapoor's works, culminating with his masterpiece, the monster called "Leviathan", displayed at the Grand Palais of Paris.

FIG. 3.1: LEVIATHAN, ANISH KAPOOR, GRAND PALAIS, 2011

For all these reasons, to become familiar with the construction system, several digital models have been designed with 3D software and then manufactured at real scale by this author. The main goal was to learn how to design, control, shape and manufacture inflatable and Tensairity® girders.

FIG. 3.2: INFLATABLE HOUSE, ALTRO STUDIO, (2001)

The principal issues relating to the design and manufacturing of inflatable elements were identified and, in a second stage, studied in depth[1].

It appears clear that the majority of inflatable systems are based on simple modular shapes. Linear elements, for example, are usually designed straight or symmetrical and later connected and arranged in a way to create the desired shape. Although an endless variety of shapes can be produced in this way, the potential of inflatable structures has not yet been pushed to the limit. As a result, the majority of complex shapes realized with these technologies end up as a poor approximation of the original concept.

Factors that influence the quality of the final results range from form-finding calculation to cutting pattern generation and the manufacturing of seams. If, in the case of leisure or advertising applications, these factors may be negligible, when inflatables are asked to address structural functions, they cannot be avoided. The following chapters will take them into consideration.

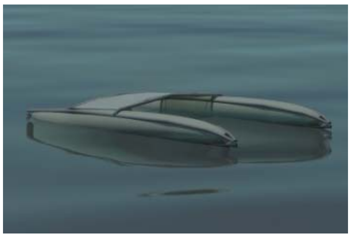


FIG. 3.3: CONCEPT FOR AN INFLATABLE CATAMARAN "KITE-CAT"

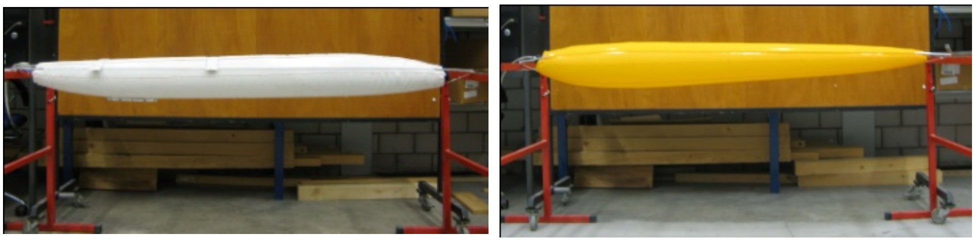


FIG. 3.4-5: MOCK-UPS TO STUDY THE FORM FINDING OF INFLATABLE TENSAIRITY® HULLS

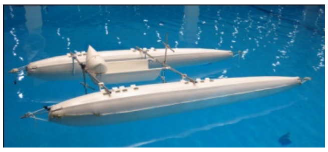


FIG. 3.6: TEST OF THE TENSAIRITY® CATAMARAN

To focus the research better, the construction of inflatable Tensairity® hulls for an easily transportable catamaran were developed as a first approach to inflatable technology. Despite the simplicity of the goal, the research investigated the software available on the market to calculate form, analyse its behaviour and generate the panels ready for production. Investigation into a simplified design methodology for inflatable structures is described[2] together with an overview of the manufacturing processes for such kinds of structure.

3.1.1. Design investigations of inflatable components

Even if inflatable structures obey strict and well-known rules of equilibrium, the definition of complex shapes nonetheless remains a challenge.

Struts, webs or cables can be used to turn round-shaped pneumatics into complex-shaped inflatables. The designer needs to define and control complex 3D free forms and, at the same time, to predict the behaviour of such forms under the load of pressure, while interactions between membranes, struts, webs and cables all have to be taken into account

---

[1] Carra G., Beccarelli P., Maffei R., (2012), *Interaction between fibre-glass profiles and membranes for building active tensile structures*, IASS-APCS 2012, Seoul.

[2] Maffei R., Carra G., Beccarelli P., Galliot C., Zanelli A., (2012) *Design of complex inflatable shapes and geometrical analysis of pneumatic structures*, IASS-APCS 2012, Seoul.

too. This process is still currently based on a “trial-and-error approach”. The design process relies on sketching and then manufacturing scale models in paper or other materials. This empirical approach requires time, money for the prototypes, and is based on personal experience, which can rarely be transferred. This is probably one of the reasons why applications of these kinds of structure are rare.

A brief excursion to define a design methodology for lightweight structures in the particular case of inflatable structure is presented in the following paragraphs. A background of basic formulas together with an overview of software and parametric design methods that can speed up the process from the conception of the idea to the manufacturing of the final product will be described.

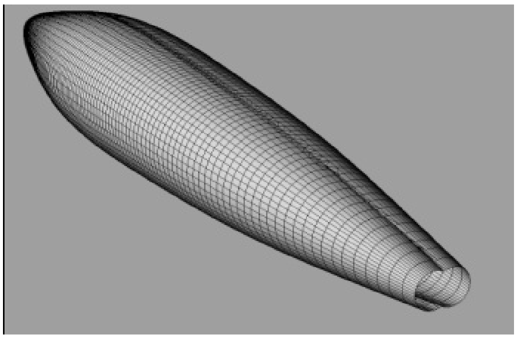


FIG. 3.7: EXAMPLE OF TENSAIRITY® HULL GENERATED PARAMETRICALLY

Basic formulas

Defining the shape of an inflatable structure is not an easy task. Pneumatic structures are form-resisting thus their shapes follow specific and well-known rules of equilibrium[3].

The equilibrium of a membrane structure supported by air can be calculated by applying thin wall vessel formulas for both spheres and cylinders. In the case of the cylinder, for reasons of symmetry, the stresses on a small stress element are different in longitudinal and hoop directions. To determine the longitudinal stress σ, we make a cut across the cylinder. Since the vessel is under static equilibrium, it must satisfy Newton’s law of motion, hence the stress around the wall must be equal to the internal pressure across the cross-section (1).

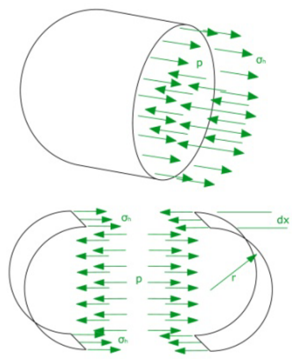


FIG. 3.8: PRESSURE IN CYLINDER VESSEL

$$p = \sigma u/ru + \sigma v/rv \qquad (1)$$

WITH:

- σ: *SURFACE STRESS [N/MM²]*
- P: *INTERNAL GAUGE PRESSURE [N/MM²]*
- R: *INNER RADIUS OF THE VESSEL [MM]*
- T: *WALL THICKNESS [MM]*

To determine the hoop stress σ_h, we make a cut along the longitudinal axis and extract a small slice. The free body is in static equilibrium. In accordance with Newton's first law of motion, the hoop stress can be calculated (2) and it is quickly shown that the hoop stress is twice the longitudinal one.

$$\sigma * t * 2\pi r = p * \pi r^2 \rightarrow \ \sigma = pr/2t \qquad (2)$$

3 Lennon A., (2008), *Geometrical Mechanics for Inflatable Structures,* Fourth European Workshop on Inflatable Space Structures, ESTEC, Noordwijk, Netherlands

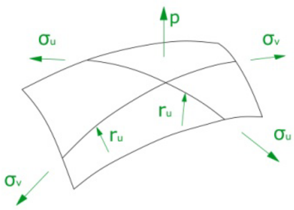


FIG. 3.9: STRESS DIAGRAM

WITH:
σU, σV: SURFACE STRESS [N/MM] IN THE PRINCIPAL CURVATURE OR IN WARP AND WEFT DIRECTIONS
P: INTERNAL PRESSURE [N/MM²]
RU, RV: INNER RADIUS [MM] IN THE PRINCIPAL CURVATURE OR IN WARP AND WEFT DIRECTIONS

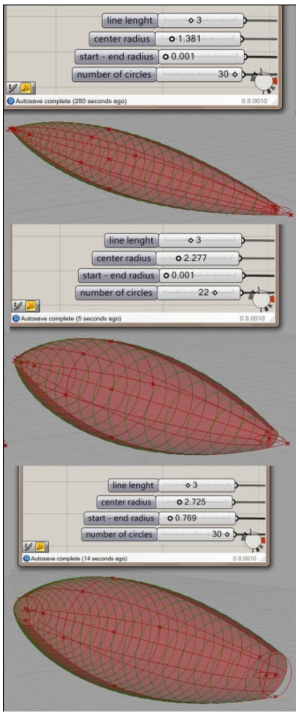


FIG. 3.10: PARAMETERS OF THE TENSAIRITY® HULL

In a general form, a pneumatic structure always follows the formula (3):

$$2 * \sigma_h * t * dx = p * 2 * r * dx \rightarrow \sigma_h = pr/t \qquad (3)$$

Following these rules three types of inflatable structures can be defined: the air-supported hall (single layer) the cushion structure (double layer with rigid boundaries) and the air-beam structure (double layer without rigid boundaries)[4]. The following analysis focuses specifically on the third case: the design of air-beam elements trying to go beyond the existing shapes which are based on simple solids such as cylinders or cigars.

Design methodology

Parametric design is an effective strategy to define and control boundary conditions especially when they actively affect the final geometry. This is the case of form-resisting structures, specifically, of inflatable designs. Parameterization of both form and boundary conditions would allow a faster and easier approach to the design of inflatable structures and would partially substitute the use of real scale models[5]. Real scale models are money- and time-consuming and, most of the time, inaccurate due to the difficulties in reproducing the behaviour of materials and connections when scaled.

In the case of membrane structures, where the final configuration is a matter of equilibrium between the forces in the membrane and the boundaries, parameterization of the geometry only at the borders (boundary conditions) would not improve the design process that much. Simulations of flexible mechanical structures in the fields of analysis, design and control are generally based on the finite element method which requires specific knowhow.

Some alternative methods that integrate structural flexibility and control from the very beginning of the design process have been developed. In these models, two different disciplines are combined to achieve an optimal design: form-finding which determines the structural shape of tensile structures from an inverse formulation of equilibrium, as well as general structural optimization based on non-linear mathematical programming[6].

These approaches open up endless design possibilities and could dramatically speed up the process from the very beginning. However, due to the complexity of the software, final users remain in the field of structural mechanics, therefore, simplified methods that can be used by architects and designers are needed to spread the application of inflatable technology more quickly.

[4] Herzog T., (1977), *Pneumatic structures: a handbook for the Architect and Engineer*, Crosby Lockwood, London.

[5] Mirtschin J. (2011) *Generative Models Utilized for Superior Design Development* International Symposia IABSE-IASS 2011: Taller, Longer, Lighter, London.

[6] Fischer M., Bletzinger K.-U., Wüchner R., (2010) *FE-Simulation and Optimal Design of Smart Adaptive Lightweight Structures*, Proceeding of the ECCM2010, IV European Conference on Computational Mechanics Palais des Congrès, Paris.

SIMPLIFIED DESIGN APPROACH

A simplified approach in this direction has been tested through the application of physic-like tools which are now available and can be implemented into free plug-ins, such as Grasshopper®[7] for Rhinoceros®[8]. Some of these plug-ins are able to compute the interaction between particles, simulating, with a certain degree of accuracy, different forces, and even the behaviour of complex shapes under pressure. These tools are easy to handle and can give the designer a quick overview of the response of complex structures under dynamic load conditions too. Some of these tools have been explored for the designing of the Tensairity® hulls, and their potential and accuracy have been verified by comparing 3D simulations and real models[9].

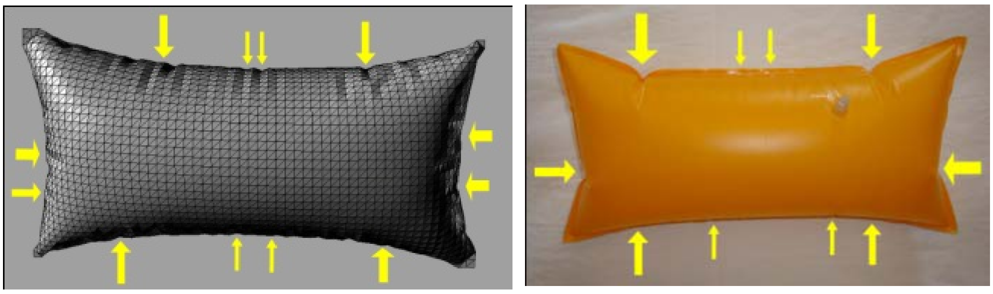


FIG. 3.11-12: COMPARISON BETWEEN 3D SIMULATIONS AND REAL MODELS

3.1.2. Form finding and cutting pattern of pneumatic structures

"Form-finding" is a process to generate an optimal configuration from structural and visual points of view in given stress distribution and boundary conditions acting on a flexible structure[10].

The world of form-finding is vast. The first experiments based on reverse models such as the one by Gaudì for the Sagrada Familia or the soap bubbles studied by Frei Otto, are now outdated even if they remain important sources of inspiration. At the present time, to define the equilibrium of complex membrane shapes, dedicated software is usually required. In these software products, forms are defined through a process of "form-finding", in which prescribed boundary conditions and stress distribution are the driving degree of freedom in the design process, in contrast with standard mechanics where stresses are the structural response to the deformation of the material[11].

PROCESS OF FORM-FIND

Form-finding algorithms calculate the equilibrium of an envelope that behaves as a soap bubble according to a certain level of pretension (both in warp and weft directions) and the

[7] www.grasshopper3d.com

[8] www.rhino3d.com

[9] Maffei R., Luchsinger R., Zanelli A., (2011) *Design tools for inflatable structures, International Conference on Textile Composites and Inflatable Structures,* Structural Membranes, Barcelona

[10] Bletzinger K.-U., (1998), *Formfinding and Optimization of Membranes and Minimal Surfaces Formfinding with the Updated Reference Strategy (URS),* Lecture notes, prepared for the PhD-course: Advanced school on Advanced Topics In Structural Optimization.

[11] Lewis W. J., (2003), Tension structures: form and behaviour, Thomas Telford, London

boundary condition (geometry and rigidity of the perimeter and anchor points) defined before simulation begins.

Several types of software are able to generate equilibrated shapes by applying different form-finding algorithms[12]. The advantages of these tools derive from the proven stability of the algorithms and general acceptance by the scientific community. Unfortunately, a few inconveniences are also related to this design approach.

First of all, the modelling process in these programs is not user-friendly and requires a certain level of experience to avoid unpredictable behaviour and mistakes. Secondly, the calculation time for complex geometry can be extremely CPU-intensive. Moreover, real time control of the simulation is not available, thus the time for the design process increases. In addition, the geometrical limitations are sometimes very strict. Geometries can be imported, of course, from other dedicated CAD files, however well-known problems of compatibility arise.

As a consequence, it is clear that designers and architects are usually not skilled enough to deal with these programmes and this is why inflatable projects are mainly ordered from engineering firms with consequent additional costs and a slowdown in the design processes. For these reasons, a simplified tool and a proven design methodology would allow designers and architects to come up with a reasonable preliminary design that would speed up the whole design process and avoid the most naive mistakes.

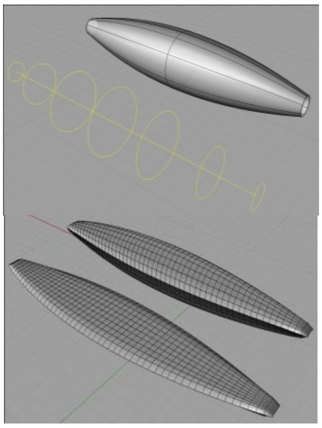


FIG. 3.13: CROSS SECTION AND ENVELOPE APPROACHES

In the particular case of inflatable structures, a simplified form-finding approach can be identified. Even complex shapes can be made by connecting and intersecting several basic geometrical shapes. Each of these basic geometrical shapes presents circular or semi-circular sections. The definition of the exact position of these circular sections and, sometimes, their deformations due to the interaction with boundary conditions, such as inner or outer struts or cables, is a crucial task in designing an inflatable structure precisely. The higher the number of circular sections that can be defined, the more accurate the prediction of the shape of the pneumatic structure will be. Unfortunately, in most cases, only a few circular sections are known in advance, especially where the structure is complex.

TWO DESIGN APPROACHES

In this way, two different design approaches for pneumatic structures can be identified. In the first case, which could be called the “cross-section approach”, the designer should look for the circles or portions of circles that will be generated by the inflation, set these as strict boundary conditions, and generate the shape out of these boundaries. This approach requires time and extensive geometrical abstraction capacities. The results are accurate but complex shapes are tricky to produce.

In the second case, which could be called the “envelope approach”, the designer should look for the envelope to be inflated and then, using specific scripts, simulate its final

[12] Lewis, W. J., Lewis, T. S., (1996), *Application of Formian and dynamic relaxation to the form finding of minimal surfaces*, Journal of the IASS, Vol 37, pp 165-186

configuration under the load of overpressure. In this case, complex shapes can be generated, however the quality of the results needs to be verified.

These two approaches are different but complementary: the first requires a clear idea of the final shape one has in mind; the second focuses on the flat envelope before inflation. The first can be done using simple CAD systems or even by hand; the second requires specific software and plug-ins (in this dissertation the use of Grasshopper for Rhino was considered). The first is more theoretical, the second reproduces virtually what is usually done by hand, building up 3D models out of a flat sheet of textile.

The first case focuses more on the end results, the second gives a better feeling of the possibility of manufacturing and constructing a complex shape. In some cases, both approaches would be required: first the “envelope approach” would target the shape roughly and help define the position of the circular sections; secondly, the “cross-section approach” would generate the final shape with better accuracy. The following paragraphs will briefly describe both methods and their application in design practice.

***Cross-section approach*.**

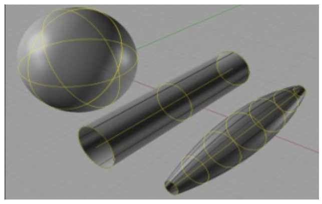


FIG. 3.14: GENERATION OF BASIC SHAPES FROM LINEAR AXIS

Any envelope, under the load of inner pressure, tries to accommodate most of its cross-sections in the shape of circles or portions of circles. According to different boundary conditions such as border connections, inner or outer springs or struts, these sections deform and then become more difficult to identify.

The simplest pneumatic shape is the sphere: on it, an infinite number of circles with their centres at the centre of the sphere can be identified. In a cylinder, infinite circular sections are placed, normally, along the axis of the cylinder itself. In the case of a spindle, the radii of the circles vary along the length of the axis. If the axis is not a straight line but a generic curve, more complex shapes can be defined. Cylinder-arches or spindle-arches are generated if the axis is an arc. In a similar way, a torus can be defined if circular sections are positioned normally to a circle.

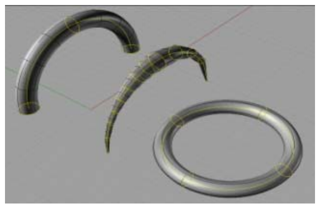


FIG. 3.15: GENERATION OF BASIC SHAPES FROM CURVED AXIS

Symmetrical and asymmetrical elements can be designed with this approach by scaling and rotating circular sections (the axis in this case would be a generic curve or a “spline”) at specific points. Starting from these simple considerations and connecting together primitive forms, a large number of more complex shapes can be obtained. The final configuration can be predicted by the simple combination of each primitive form as long as no extra deformations occur at the connection points.

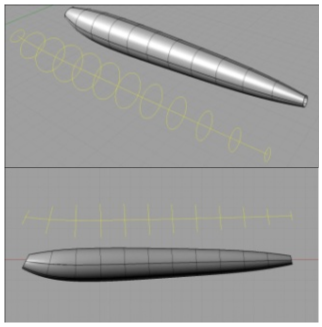


FIG. 3.16: ASYMMETRICAL LINEAR PNEUMATIC ELEMENTS

The design of inflatable products in the construction industry is 90% based on the “cross-section approach”. The limitations of this method are evident: all those shapes in which the position and geometry of the cross sections are difficult to predict cannot be designed precisely; complex and spatial shapes are problematic. The advantages of this approach are the fact that the knowhow required is basic and only related to simple geometry: any basic CAD system can solve it and, sometimes, hand sketches are quite sufficient.

Envelope approach

Sometimes it is not possible to identify in advance circular sections that can be set as fixed boundary conditions to define the final shape of a pneumatic structure. Moreover, in some cases, designers would like to investigate what an envelope would look like under inflation without bothering with the construction of handmade models. Handmade models cost time and effort and their behaviour is strongly dependent on their size, the properties of the materials used, the accuracy of the model itself and the definition of the cutting pattern for production[13]. This is why the envelope approach can provide an answer to those who would like to explore the world of pneumatics starting from the envelope itself. A process of trial and error guides the designer to achieve the final shape, and maybe in the near future, it can help designers control the entire inflation process of, for example, a folded pneumatic element. At the moment, inflation processes, for example for applications in space, are studied by means of complex finite element analysis[14]. This is definitely not a tool that architects or designers could use for their purposes.

Sometimes, even simple shapes are tricky to define using the cross-section approach. This is the case of a simple pneumatic pillow generated by the inflation of a flat rectangular peace of membrane; this simple shape that everybody has in mind is something that cannot be modelled accurately (especially at the four corners) merely by applying the cross-section approach. In the case of a cushion with several holes, the identification of the circular sections becomes even more difficult or, sometimes impossible. On the other hand, designers like Architects of Air (AOA), generate these shapes based on their experience, however even for them a new design would require weeks of work and, in the end, the result might not be accurately predicted.

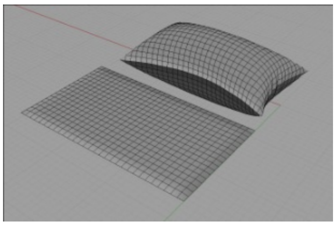


FIG. 3.17: PILLOW AS INFLATION OF A RECTANGULAR MESH

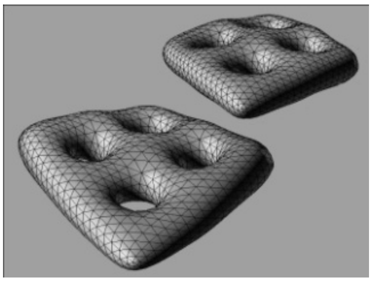
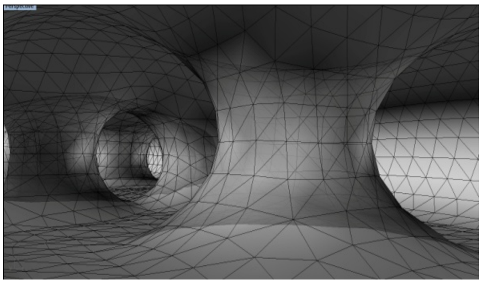


FIG. 3.18: PILLOWS WITH HOLES, TWO CONFIGURATIONS



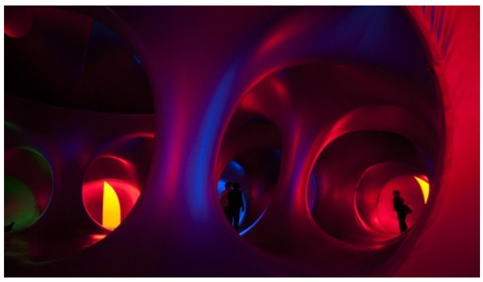


FIG. 3.19-20: INNER SPACE OF AN INFLATABLE: SIMULATION COMPARED WITH THE ART PAVILION AMACOCO BY AOA

The generation of the inflation process for the meshes illustrated in this dissertation was made using a plug-in for GH called Kangaroo Physics®.

---

13 Herzog T., (1977), *Pneumatic structures: a handbook for the Architect and Engineer*, Crosby Lockwood, London.

14 Lou C. M., (2004), *Development and application of space inflatable structures*, 22nd International Symposium on Space Technology and Science, Morioka, Japan.

Kangaroo is an add-on for GH/Rhino which embeds the physical behaviour directly in the 3D modelling environment and allows live interaction with the model when the simulation is running. It is used for various sorts of optimization – structural analysis, animation, and much more. Kangaroo simulates physical behaviour by applying the particle system. Particles are objects that have mass, position, and velocity, and respond to forces, but have no spatial extent[15]. The behaviour of particles and their interaction follow Newton's law. For example, a flat sheet of membrane can be represented by a grid of particles that are connected together with springs. Springs can be used in two orthogonal directions only. If some shear stiffness is required then diagonal springs may be introduced. It is also possible to obtain different types of behaviour by using damped springs; further information can be found in the manual[16].

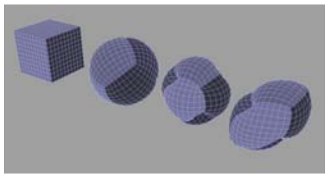


FIG. 3.21: DEFORMATION OF AN INFLATED BOX

FIG. 3.22: INFLATABLE CLOUD

Of course, this concept has many limitations in comparison to finite element analysis, however it can resolve some simple engineering problems.

To design complex inflatable shapes, a generative algorithm can be applied and connected to the evolutionary solver Kangaroo Physic to define the final shape under the load of pressure. Boundary conditions can be made as complex as the designer wants and the real-time visualization can help to understand what boundary conditions are driving the equilibrium of the final shape. Reducing the restraint of the conserving surface area, several shapes can be achieved, and complex shapes that follow the rules of inflatable structures can be generated. Inner rods or struts can be modelled and the interaction between them and the envelope taken into account.

The examples shown in figure 3.21 are generated by applying a high level of stiffness to the envelope, but no bending stiffness. This approach can be useful in defining the inflation behaviour of an envelope manufactured without any cutting pattern or with a really simple one. The majority of inflatable structures, due to lack of knowhow and speed in manufacture, end up being built in this way.

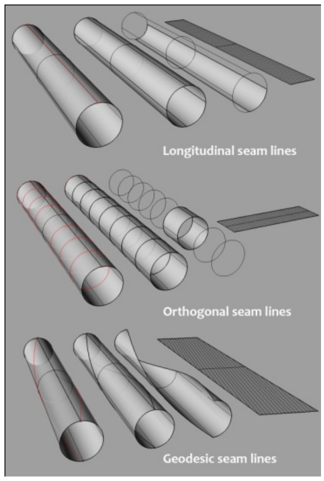


FIG. 3.23: EXAMPLES OF ARRANGEMENTS OF SEAM LINES

Cutting pattern

To be able to produce a smooth, precise and wrinkle-free double curvature surface out of flat panels the generation of a cutting pattern is required[17]. Cutting patterns start from the definition of seam lines and continue with the flattening of the panels. Flattening is a process of simplification that leads to errors of approximation[18]. These errors are minimized

---

15 Witkin A., (1997), *Physically Based Modelling: Principles and Practice*, *Particle System Dynamics,* Robotics Institute, Carnegie Mellon University.

16 www.grasshopper3d.com/group/kangaroo

17 Gründig L., Moncrieff E., Singer P and Ströbel D., (2000), *High performance cutting pattern generation of architectural textile structures*, IASS-ICAM, Fourth International Colloquium on Computation of Shell & Spatial Structures, Crete, Greece.

18 Punurai W., Tongpool W., Morales J. H., (2012), *Implementation of genetic algorithm for optimum cutting pattern generation of wrinkle free finishing membrane structures*, in Finite Elements in Analysis and Design, Vol. 58 pp. 84-90

thanks to advanced algorithms now applied in several commercial software[19] or, at least, controlled in the case of development through the abovementioned parametric tools.

More important than the flattening phase is the process of seam definition which has aesthetic and stability influences on the final result.

In seam arrangement it is necessary to take into consideration how slices will be assembled at the moment of manufacturing thereby saving time during the welding or stitching phase and reducing any waste of material.

The seam lines themselves are defined starting from surface lines. There are four main types of surface line, as defined in the literature[20]: planar, irregular, geodesic and semi-geodesic. Planar and irregular lines do not need explanation, geodesic are known to be the shortest lines between two points on any given surface but there is something more. This characteristic of minimizing the length of connection is not the only advantage of using such lines as seams. Geodesic lines have the property that as they pass over a surface, they do not curve in the tangential plane. Consequently, a surface properly patterned on the basis of geodesic lines can mean cloths which minimise cloth usage as well as the angles between the textile weave and the surface principle stresses.

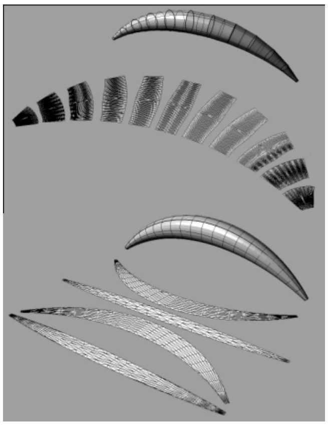


FIG. 3.24: EXAMPLES OF POSSIBLE CUTTING PATTERN OF AN INFLATABLE ARCH

Meanwhile, semi-geodesic lines are lines which are geodesic between the points they connect that may also be inside the surface, not only along its edges as happens for standard geodesic lines. These lines can be useful, for example, in inflatable structures where geodesic lines, especially at the end caps, turn into something unexpected.

Nonetheless, using only geodesic or semi-geodesic lines a lot of different seam arrangements can be identified. The choice is in the hands of the designer who must look carefully at the final aesthetic result but also at the manufacturing phase.

One clear example derives from the cutting pattern of an inflatable arch-hull (figure 3.24). There are at least two straightforward methods to generate flat panels out of an arch-shaped inflatable. In the first case, the cuts are orthogonal to the axis of the arch. The resulting panels are linear, similar to each other, and easy to connect due to the (almost) straight seam lines. The higher the number of cuts, the higher the accuracy of the final result, but the higher the cost of manufacturing in terms of time, due to the large amount of welding.

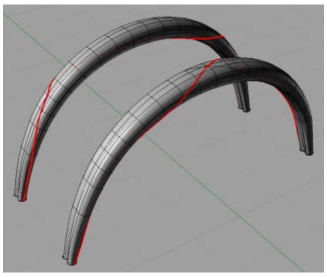


FIG. 3.25: STUDY OF SEMI-GEODESIC LINES INFLATABLE ARCH

In the second case, the cuts follow the main direction of the arch. In this case, fewer panels are generated and they differ consistently one from another. Production is much more difficult due to seam lines which are not parallel, and in fact sometimes diverge. On the contrary, the number of seam lines is dramatically reduced and the result is much more pleasing from an aesthetic point of view. In addition, in the case of pneumatic structures, we need to take into consideration how to close the inflatable and keep it airtight.

---

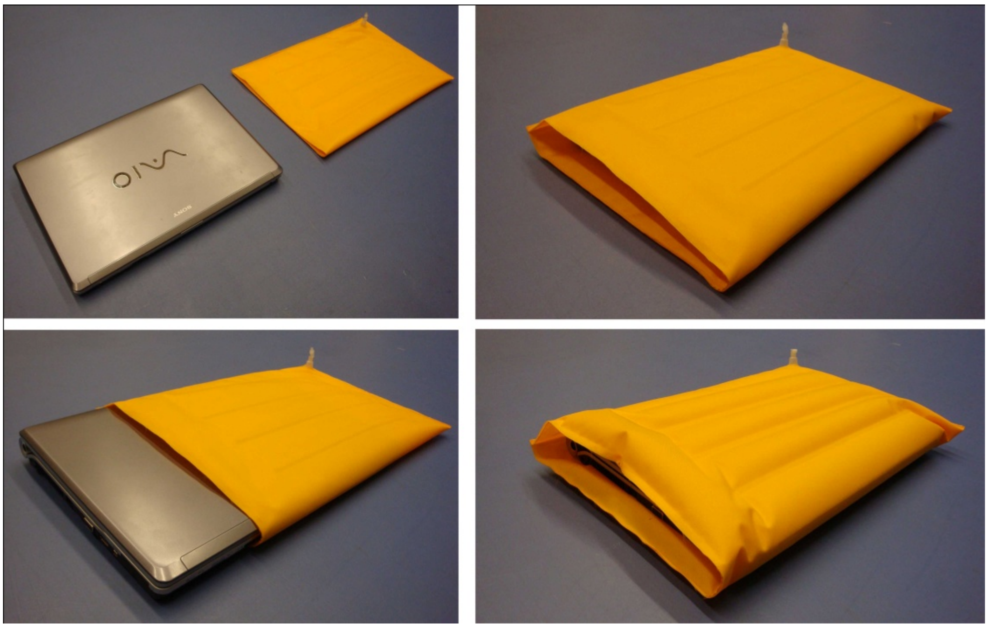
19 Ströbel D., Singer P., (2007), *New Developments for cutting pattern of membranes,* Proceeding of the conference Structural Membranes, Barcelona

20 Gründig L., Ekert L., Moncrieff E., (1996) *Geodesic and Semi-Geodesic Line Algorithms for Cutting Pattern Generation of Architectural Textile Structures,* in Lan, T.T., (Ed.), proceedings of Asia-Pacific conference on shell and spatial Structures IASS, Beijing, China.

The seam arrangement, cutting pattern and production methods which avoid these steps will be further investigated in depth in Chapter four.

3.1.3. Construction of mock-ups

To prove the accuracy of the abovementioned tools, several mock-ups were build and their manufacturing possibilities tested. Even if, at the beginning, the definition of a parametric 3D model requires more time, once the model is ready, any modification takes a matter of few seconds therefore, the overall time dedicated to geometric definition, form finding and pattern cutting is dramatically reduced especially when subsequent modifications have to be made.



FIGS. 3.26-27-28-29: INFLATABLE BAG FOR LAPTOP

FIG. 3.30-31: INFLATABLE CASE FOR GLASSES

BOTTLENECK SHIFTED FROM DESIGN TO PRODUCTION

Moreover, the these design tools push the user to organize and create his/her own library of tools which can be applied to specific circumstances, when needed. As a result, the bottlenecks have been shifted from the design to the manufacturing phase which, most of the time, requires expertises and tricks one cannot pick up in just a few months.

The fields of application of these tests were small- and medium-sized components for leisure and sports activities, such as a prototypes for an inflatable Tensairity® hulls for a transportable catamaran. Some prototypes in the packaging field were manufactured too (figures 3.26-3.31). In those cases, the combination of membrane and air was able to give its contribution to protect a delicate object. To answer the function of protection, inflatable packaging needs to be shaped correctly and should be able to withstand a certain degree of stiffness. This is why variations of the Tensairity® principle have been applied as reinforcement for inflatable cases for laptops or glasses.

Mock-ups clearly showed the importance of accuracy in the definition of the membrane but much more, how crucial are details, joints and connections which have to interact with textiles (see Chapter Five).

3.1.4. Design of a tensile structure: tensioning a tarp

If, in inflatable structure, the pre-stressing of the membrane is demanded from air pressure, in tensile structures, fabric is tensioned at the design load through other means such as point or linear anchorages together with stretching systems.

In the field of emergencies, the task of tensioning a single tarpaulin (4x6m) in the correct way would solve the majority of the problems which affect humanitarian assistance at least for the first 48-72 hours, however, it is no easy task. The challenge is to find a way to tension a flat sheet and give it a shape that can withstand wind load and drain away rain. The world of lightweight constructions, especially regarding the field of tensile structures, says that membranes are to resist structure therefore tensioning should focus on the definition of the correct shape to come up with the required load resistance. Form-resistant structures are mainly based on double curvature surfaces which are classified and discussed widely in the literature[21].

FIG. 3.32: HOW TO INTRODUCE TENSION IN A FLAT TARP, S(P)EEDKITS WORKSHOP 2012

Double curvature surfaces are optimized for a given load stress distribution in both the warp and weft directions. These surface are manufactured through a cutting pattern process which defines fabrics that are generally curved. The result is a 3D surface which becomes rigid as soon as the pre-tension load is applied. but unfortunately, in the case of tarpaulin, both practitioners and locals need to deal with a 2D surface which will never be stable.

Introducing a double curvature in a flat surface can be done by different means. As for inflatables, internal air is the medium to generate the double curvature, while tensile structures uses external anchor points, located at different heights.

Experiments into the tensioning of tarpaulins have been carried out as part of the European S(p)eedkits project: in this case, the double curvature was generated through the use of elastic profiles (FRP). Introducing a low curvature was possible with effective results. High curvatures, on the contrary, did not generate the expected results.

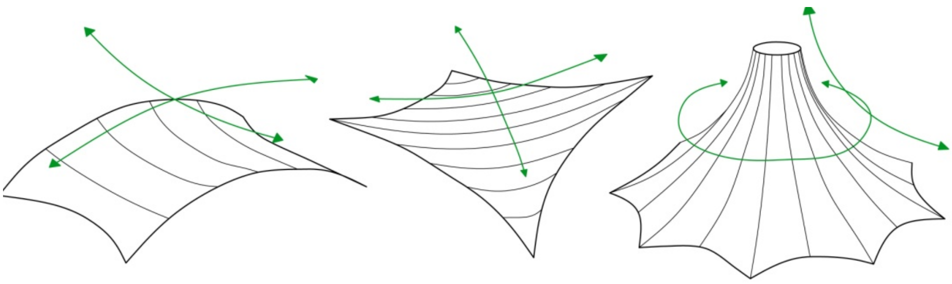


FIG. 3.33: DOUBLE CURVATURE BASIC SHAPES

[21] Herzog T., (1977), *Pneumatic structures: a handbook for the Architect and Engineer*, Crosby Lockwood, London.

The combination of inflatable linear elements and tarpaulins, with the aim of introducing a pre-stress in the flat sheet thanks to the deformation deriving from the inflation of the air chamber, would be a smart yet simple answer to the abovementioned problems.

3.2. Design of a multipurpose, implementable and open structural component

It seems to be a common understanding among humanitarian actors, as presented in the conclusions of Part One of this dissertation, that linking relief and reconstruction/development (not only in the field of sheltering) is one of the major challenges to be addressed by humanitarians. At the present time, this has mainly meant the application of processes to guide the affected community from the relief phase towards development.

This author thinks differently. As demonstrated extensively in Part One, both NGOs and local authorities find it hard to foresee how the processes will evolve in an emergency occasion. How is then possible "to guide" a process without knowing the direction to go in?

The complexity of the sheltering problem, from this author's point of view, can only be solved by offering and distributing effective and specific components (tools) which solve the contingency of the first hours (which is more or less universal, see Part I, Chapter Seven) but could progressively be adapted to different scenarios. These tools need to be designed as open as possible to allow implementation and adaptation according to the needs of the development phase. These improvements will be successful only if they answer two requirements:

Possibility of implementing it locally and by victims directly

1) they should be able to be implemented locally and
2) this process needs to be managed directly by the affected population.

Having on hand an open flexible tool, able to link over time the universality of the first hours of the emergency with the uniqueness of each scenario, would represent the basis of the combination of processes and products, as foreseen in the definition of sheltering.

This approach would also answer issues which arise from the action of mapping (see Part I, Chapter 2). Mapping has always been considered as the solution to address the decision-making issue, however, it has been proved how effective framework based on mapping has limits[22]. Therefore, the approach proposed in this dissertation aims to reduce the importance of "knowing all in advance" by applying an approach based on progressive solutions which are capable of "learning along the way". The myth of an omniscient designer who knows everything and applies the best solution through a top-down process is

"Knowing all in advanced" vs "Learning along the way"

[22] Peduzzi P., Dao H., Herold C., (2005*), Mapping Disastrous Natural Hazards Using Global Datasets*, in Natural Hazards, Springer

MULTIPLE ACTORS, OVER TIME, BOTTOM UP

substituted by the centrality of an open system that will be implemented by different actors over time through a bottom-up approach.

3.2.1. *ARK*: the concept

Actions in the aftermath of en emergency have been described in Chapter Seven and range from the displacement of people either to camps or collective centres, to the provision of sheltering kits with the aim of letting people built shelters close to their belongings.

DRAWBACKS OF DISPLACEMENT OF POPULATION

Looking at the two alternatives based on displacement, it is clear that both present gaps. The first case, sometimes, ends up in a poor provision of shelters that do not last long. Therefore, several subsequent distributions of goods need to be foreseen. In the second case, living in an overcrowded area, together with a large number of people, introduces additional stress which can generate chaos and a subsequent slowing down of the sheltering process too.

TRANSITIONAL SETTLEMENT APPROACH

This is why displacement action is the last option for the humanitarian sector and, in the last few years, the "transitional settlement" approach has prevailed (see Chapter Seven).

GAPS BETWEEN FIRST EMERGENCY AND TRANSITIONAL PHASE

However, the gap between the first emergency, and the provision of a dwelling meant to be transitional towards a permanent solution, has not yet been covered: the transitional solution needs days to identify and, frequently, availability of resources is not known in advanced.

Another limit of the provision of transitional shelters relates to the production and shipment of the load bearing structure which is necessarily heavier and larger in size, compared to tarpaulin. Therefore, it is not possible to rely on these for the very first emergency phase. But if the initial emergency is covered by the distribution of plastic sheeting, then most of the time this solution alone is not sufficient to provide a decent refuge.

STRUCTURAL SYSTEM

This is why, especially in large disasters and in third world countries, the humanitarian sector urgently requires a rapidly-erected structural system that can be easily distributed and set up in a few minutes to shelter victims and protect them from sun and wind for the very first hours.

A structure like this would be helpful to allow the gathering of people and to give a first sense of protection to victims in shock in a diffuse way, while allowing them to remain close to their belongings. The new solution is meant to be complementary to the plastic sheeting practice but not only: on the one hand it needs to be compatible with the established tarpaulins distribution and on the other it should be possible to integrate it with different cladding systems and/or sheltering components.

NOT DISPLACED PEOPLE OR SCATTERED COMMUNITIES

The answer is *ARK - Adaptable, Rapid, Recovery Kit* which aims to innovate the sector from several points of view.

First of all, *ARK* will make its contribution when people cannot be displaced to collective centres (for example if these are not available or are too far away). Small communities or the most vulnerable groups of people can benefit from a rapid deployable structure like this one.

Secondly, *ARK* is meant to become a tool both for victims and practitioners: based on the same system (the arch), it would be possible to construct a simple roof or, in the case of necessity, a larger and more complex collective centre. Having the same basic system shared among victims and practitioners would generate a common knowhow of the construction technology and would stimulate the participation of locals in the process of sheltering.

END USERS AND PRACTITIONERS

Thirdly, the structure is designed to behave differently over time allowing a process of implementation towards the transitional phase. Thanks to the inflatable technology, a basic load-resistant structure is provided in just a few minutes. In a second stage, and in the case of extra load (e.g. strong wind, expansion of the shelter), the structure can be reinforced with local materials such as bamboo or wooden sticks, but also metal profiles when available. In a third stage, arches can be used as moulds to be filled or sprayed with concrete or foam to create a long lasting structure.

POSSIBLE IMPLEMENTATION OF THE VERY FIRST SHELTER

When a more permanent load bearing structure becomes available, *ARK* can be 100% reused or recycled: the reinforcement struts can be used for a new dwelling, the packaging-foundation system is a bucket that can be used to collect water or to contain any sort of goods. The membrane can be deflated and reused in another place or even cut into segments and used as cladding or filled with debris and then used as a load bearing structure or dead weight.

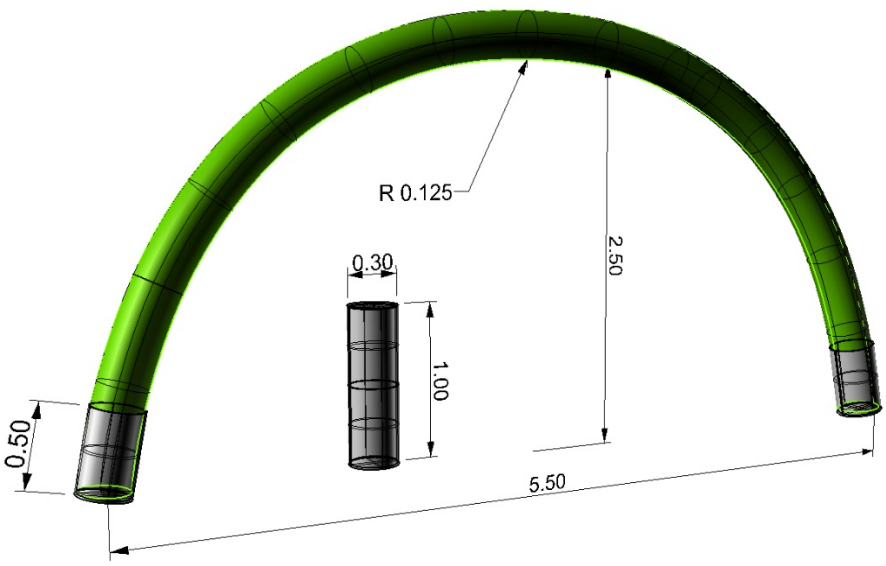


FIG. 3.34: ARK, PRELIMINARY CONCEPT

FIG. 3.35: ARK, EXAMPLE OF AGGREGATION WITH 4 ARCHES

FIG. 3.36: ARK, EXAMPLE OF AGGREGATION 2 ARCHES

Starting from this background, *ARK* aims to be a concept that simultaneously combines the process, the product and the building component.

PRODUCT LEVEL

ARK attempts to provide a range from relief to sustainable reconstruction by delivering a solution that offers affordable, simple, super-lightweight but robust stand-alone solutions for sheltering, that can be prepositioned or deployed rapidly and set up without additional technical assistance (product level).

COMPONENT LEVEL

ARK features a modular system solution that can be easily adapted and extended in number, shape and size by beneficiaries to satisfy their personal needs; at the same time, the system can be used by humanitarians to assemble a variety of relief functions (component level). It also aims to be a technical solutions for a temporary structure that can be reinforced by combining local materials (sticks, bamboo, timber, aluminium) with the inflatable arch to increase its load-bearing capacity and rigidity or to become a permanent structure based on its rigid formwork (process level).

The following paragraphs will present the peculiarity of the proposed solution in detail at all three levels.

3.2.2. Process level

From the process point of view, *ARK* has been designed to radically change the traditional approach to sheltering which is based on the distribution of products that are fixed and cannot be adapted or personalized, and to give a strong impulse to the transitional settlement approach developed over the last few years.

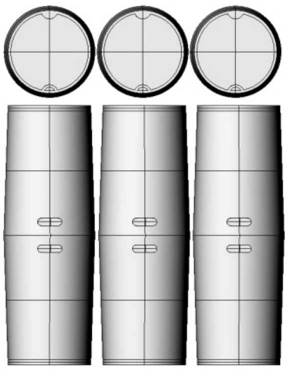


FIG. 3.37: ARK, PACKAGING

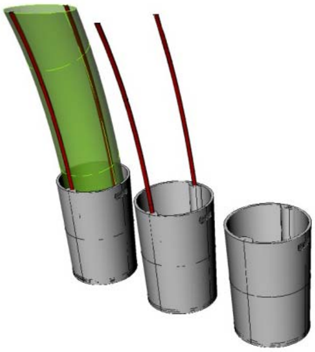


FIG. 3.38: ARK, FOUNDATION BUCKET

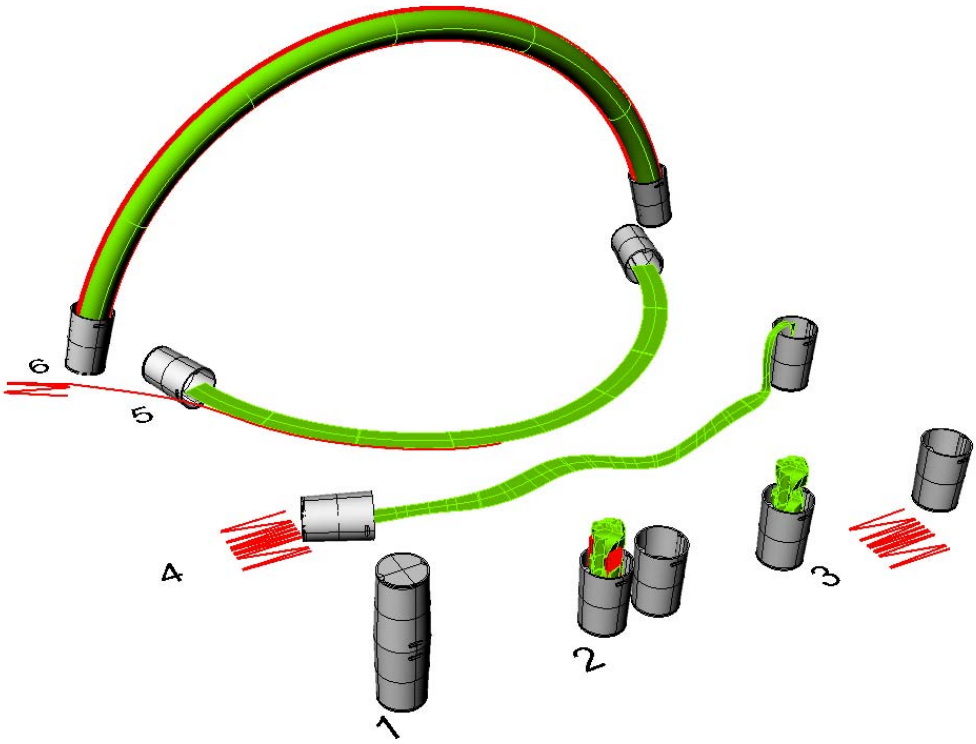


FIG. 3.39: ARK, ASSEMBLY PHASES

The results aim to combine the openness of component based systems (kits) with the advantages of the all-in-one solution (see Chapter Five).

As shown in Figures 3.39, *ARK* consists of an inflatable arch packed into a bucket which acts, at the same time, as packaging, transportation system and foundation block. The bucket splits into two parts, which become the end caps and can be filled with water or debris or even buried in the ground to improve the stabilization of the whole system. The buckets are designed to host the reinforcement struts too and to simplify the installation process.

Reinforcement struts turn a simple inflatable arch into a high performance Tensairity® arch and these elements can be included in the kit or not, according to the availability of money, the possibility of finding them on site and the expected lifetime of the intervention. Extra components, such as a hand pump to inflate the structure and straps are provided as standard and find their place in the bucket too.

ARK can supplement plastic sheeting distribution and according to the number of arches provided, different configuration can be generated.

*APPLICATIONS OF A SINGLE **ARK***

Two different kinds of direct distribution to victims have been envisaged: single or in pairs. With single distribution ARK may be applied as a stand-alone structure (stabilized with guy ropes) or used as reinforcement of an existing dwelling that may have been damaged by the hazard. A common example could be the repair of a roof blown away by a hurricane.

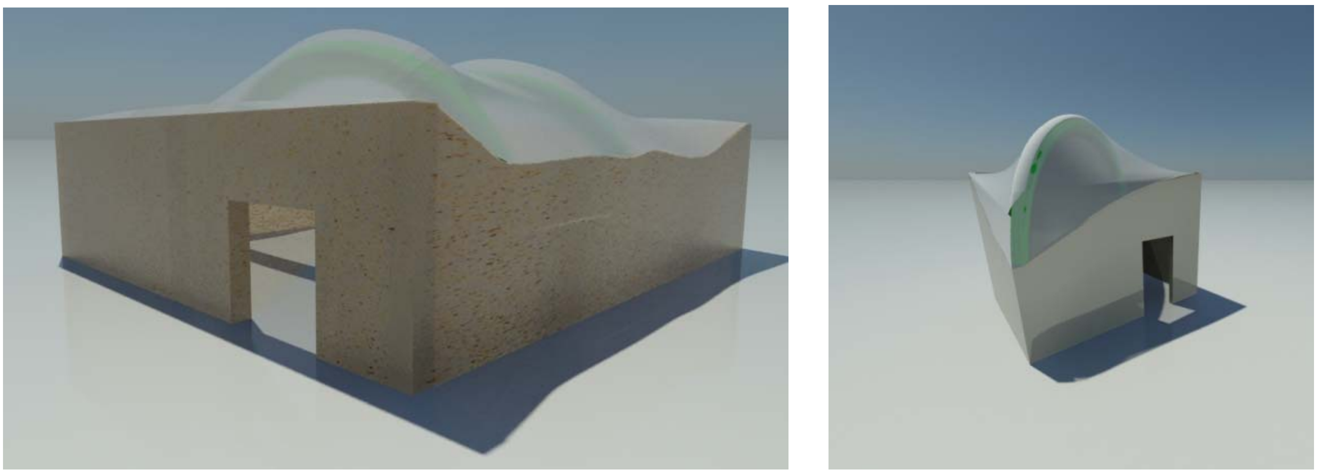


FIG. 3.40-41: ARK AS SUPPORT FOR A ROOF BLOWN AWAY BY A HURRICANE

But when a first stand-alone recovery is required, distribution in pairs is highly recommended. Based on two simple arches and a standard tarpaulin spanning them, a basic shelter can be set up in a few minutes.

*APPLICATION OF PAIRS OF **ARKS***

At a second stage, as soon as the first emergency has passed, several *ARKs* can be aggregated and upgraded over time, either by the practitioners or the beneficiaries themselves, by combining them with whatever materials they can find locally. Based on this possibility of implementation, a shelter based on ARK can be maintained and repaired easily by the beneficiaries thereby encouraging ownership and sustainable development.

In this way *ARK* has the potential to bridge the gap between emergency relief, recovery, and reconstruction in a process that gives birth to the future development of a family or community from the very first hours after an emergency has occurred.

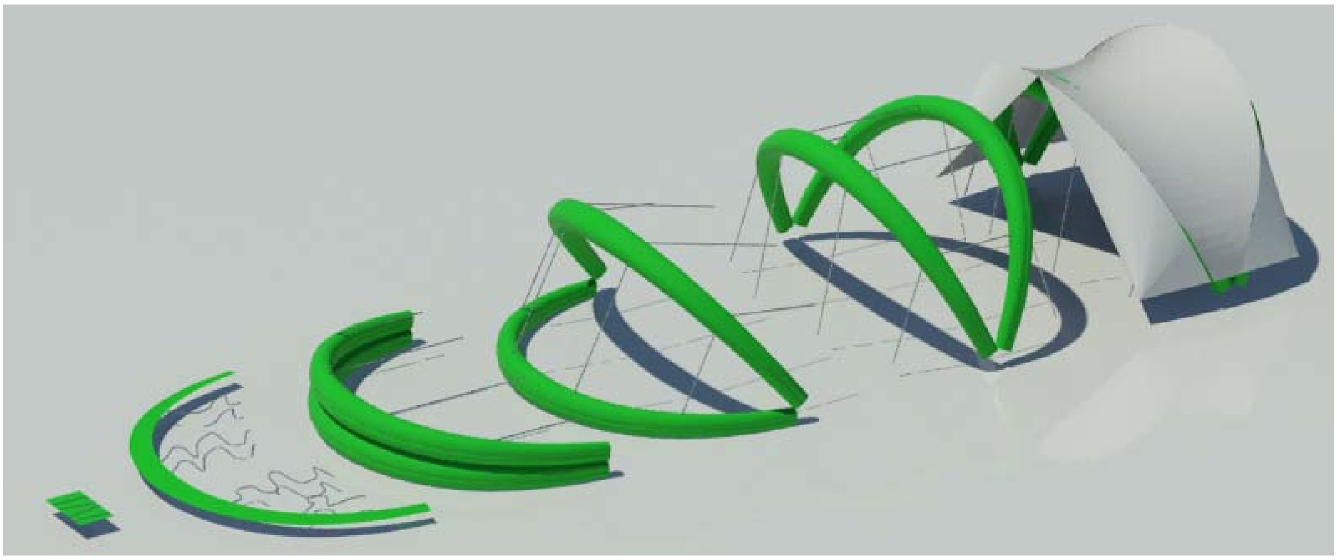


FIG. 3.42: ASSEMBLY PROCESS OF ARK, FIRST EMERGENCY CONFIGURATION

3.2.3. Product level

APPLICATION OF SEVERAL ARKS

A multiple aggregation of arches is meant for the setting up of collective or logistic centres, usually organized by volunteers and practitioners. Due to the complexity and size of these structures, construction cannot be improvised, therefore *ARK* might be integrated with another product, for example a multipurpose or hospital shelter whose requirements are set in advance. In this case the general layout and dimensions would be decided at the moment of distribution but the possibility of reinforcing the system with local materials (turning it into Tensairity®, or extending the structure are also possible. As presented in pictures 3.44/45, given a certain number of *ARKs*, several configurations can be arranged in a modular way according to need.

ADAPTABILITY

A rapidly deployable shelter based on ARK differs from standard ones in several ways. First of all, thanks to the possibility of using each component independently, the system overcomes the limits of modularity highlighted in Chapter Four. The number of arches, the number of cladding layers, reinforcements and so on can be included in the structure at the moment of shipment according to the contingency, or may even be removed and distributed to locals whenever required or when dismantling the shelter. The structure becomes much more adaptable and its components can be used and reused on endless occasions.

EASY TO REPAIR AND MAINTAIN

Secondly, *ARK* wants to reverse the idea of an inflatable as a high-tech solution that requires electricity and/or dedicated tools to inflate air tubes to the right pressure. On the contrary, the low pressure arches, especially in all the cases when the Tensairity® principle is used, can simply be set up and inflated manually, as happens with flat tyres. Repair in the case of damage uses the same technology and therefore, any community where bikes are common would be able to deal with *ARK*.

Thirdly, special products can be customized and defined based on very specific boundary conditions. Shelters able to withstand high wind loads or double layer systems to improve comfort level can be provided simply adding suitable components to the basic kit. In the same way, the quality of materials can be calibrated according to the money available and the expected duration of the intervention. Thus the portfolio of products becomes much larger than the one traditionally available.

WIDE RANGE OF PRODUCTS

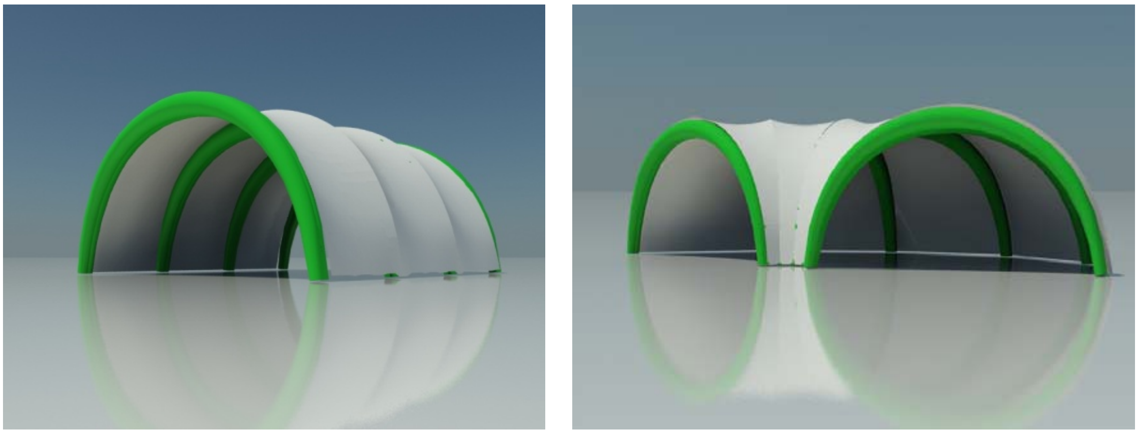


FIG. 3.44-45: EXAMPLES OF USE OF ARK AS LOAD BEARING STRUCTURE FOR A RAPID DEPLOYABLE TENT

3.2.4. Building component level

As clearly shown in the acronym, ARK is based on arch construction systems. The arch is a structural system widely used in building construction since Mesopotamian times. The arch has been identified as a promising structural system for an innovative sheltering approach for several reasons.

WALL AND ROOF AT THE SAME TIME

First of all, arch-based constructions cover roofs and walls with the same structural element. The simplicity of this system is self-evident compared with post-beam structures or other spatial-3D-frames that require careful design and manufacture of the rigid connections between the vertical, horizontal and bracing elements to ensure global stability.

SELF-EQUILIBRATED SYSTEM

Secondly, structures based on an arch system attempt to overcome the limits of tension-based structures (e.g. tents or tarpaulins) which may be lighter but require guy ropes and/or larger foundations to ensure stability.

A foundation would certainly increase the kg/m^2 ratio of these tensile structures. Moreover, as all practitioners know, a reduction in the number of guy ropes is a great advantage in terms of saving space but also as regards the usability of the surrounding of the dwellings.

In addition, the foundation of a tensioned system needs to withstand high concentrated loads which means extra cost or an extensive labour force or machinery for the installation. On the contrary, arches simply occupy the ground surface they cover. Guy ropes are placed for stabilization in the case of structures designed to last but, even without these, a first recovery area can be set up that is able to withstand low speed winds.

MULTIPLE CONFIGURATIONS

Thirdly, the modularity of the arches allows a series of multiple configurations which give practitioners and victims the opportunity to set up a shelter that is suitable for the local contest either in terms of comfort (e.g. adaptation to a certain climate) or in relation to the culture of the affected community.

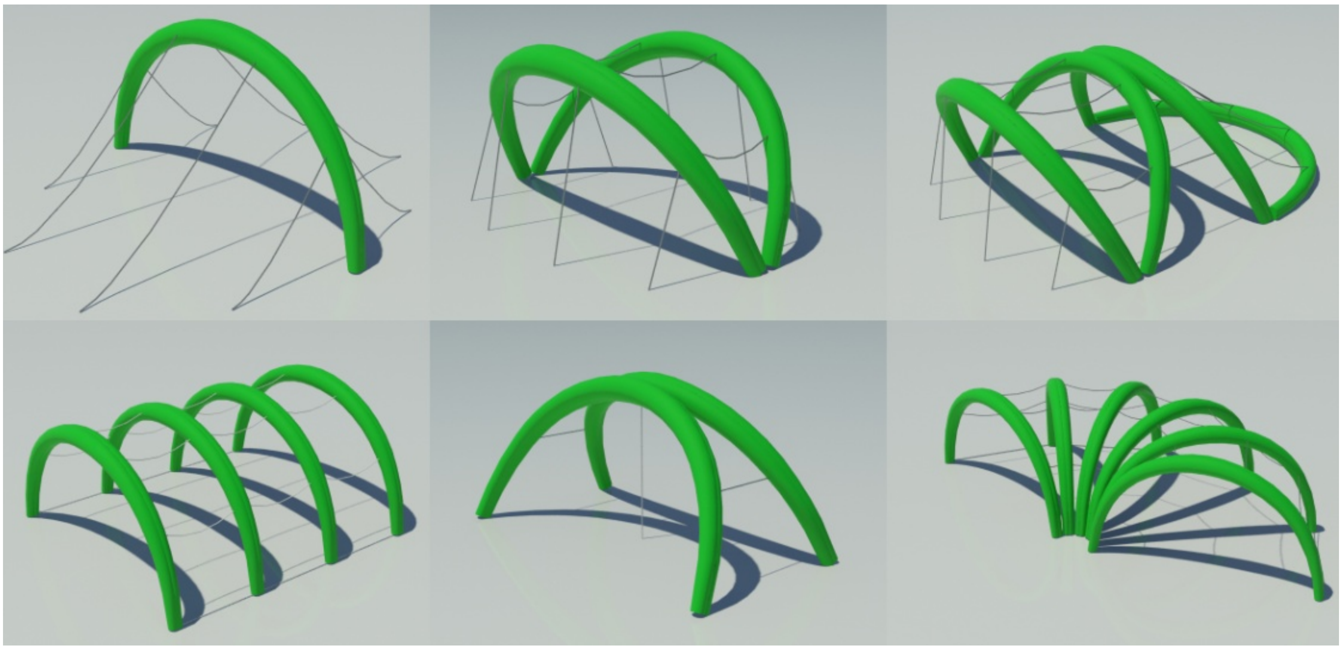


FIG. 3.47: STUDY OF ARK AGGREGATIONS

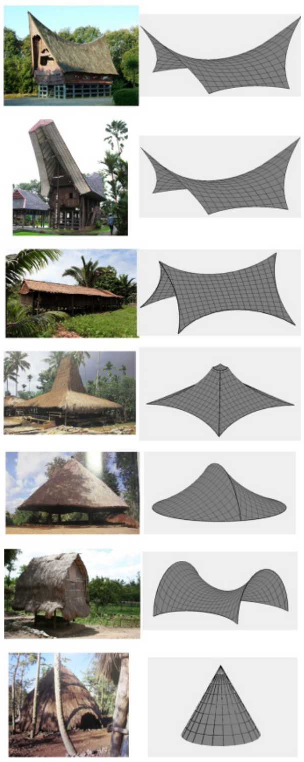


FIG. 3.47: STUDY ABOUT VERNACULAR HOUSES OF INDONESIA

From the layout point of view, several configurations are possible and picture 3.46 shows only some of the options.

The layout definition can be considered in terms of the arrangement of rooms and spaces and their aggregation in the case of more complex community shelters, but it also determines the type of shelter which is always better if it matches the cultural and social background of the affected community.

As already investigated by Martignoni et al, and presented in picture 3.46, the vernacular architecture of several countries is based on the centrality of the roofs and their forms, which can sometimes be reproduced with textile architecture technology. The main limitation of Martignoni's research is the cost and time required to build the supporting structure which does not really match the transitional settlement approach and suits the development phase better.

ARK aims to make its contribution in this direction, by offering the possibility to easily build a flexible adaptable structure. *ARK* tries to offer this flexibility thanks to its inflatable technology which can be shaped more easily than other rigid solutions.

As presented in pictures 3.48-49, the structural component of ARK works efficiently in a flexible range that allows an increase or reduction in the span/height ratio through two strategies. On the left hand side, the length of ARK varies thanks to the possibility of inflating only part of the arch, keeping a part of it rolled up and connected to the buckets. Meanwhile, on the right hand side, the length of the arch remains constant but the distance between anchorages moves. After a certain level of deformation, the arch suffers from wrinkling problem therefore its stability is compromised

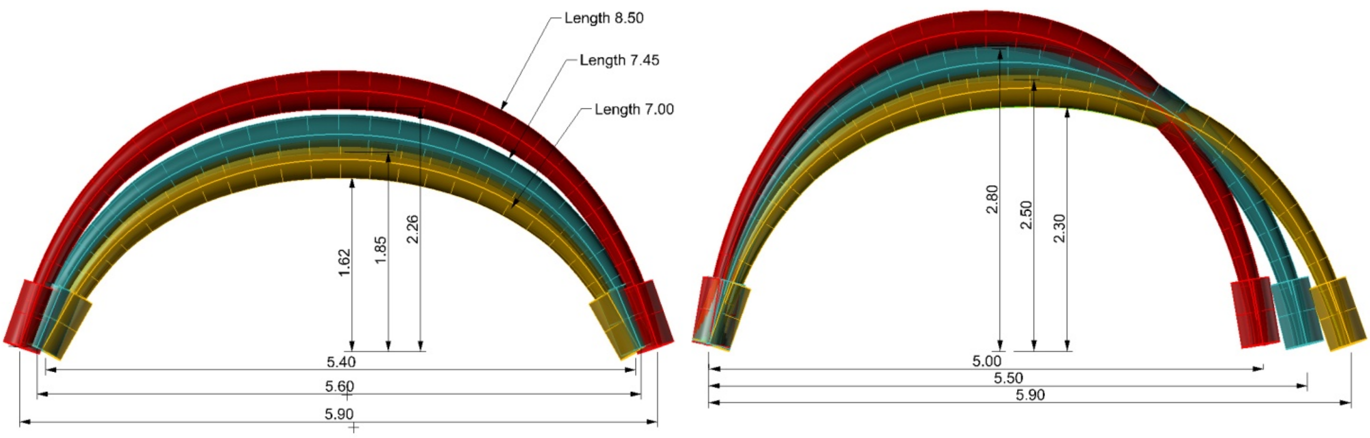
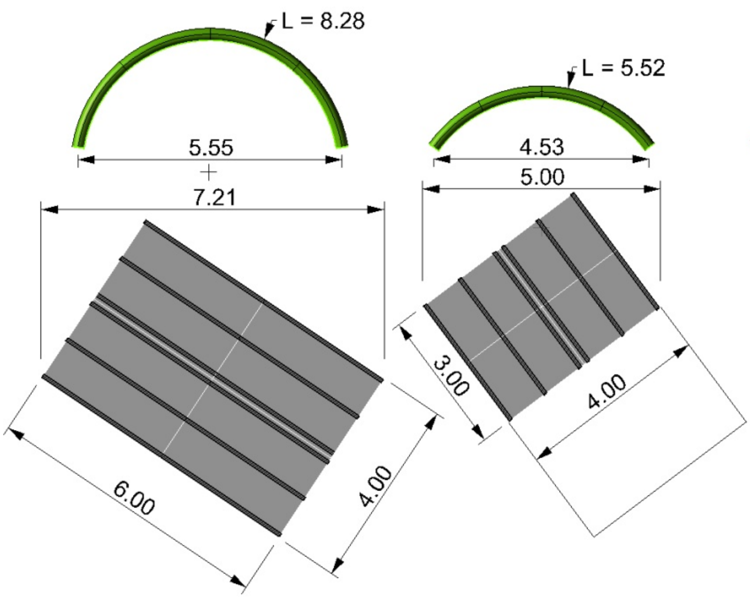


FIG. 3.48-49: RANGES OF FLEXIBILITY IN TERMS OF CURVATURE OR LENGTH OF ARK.

FIG. 3.50: NOMADIC CONSTRUCTION: YURTA

At any rate, *ARK* cannot limit its focus to the definition of the structure itself, but needs to take the cladding system into consideration too. For this reason, integration with plastic sheeting distribution is crucial. A geometrical analysis of sub modules, based on standard tarpaulin dimensions, has been carried out to identified the optimum length of the arch itself.



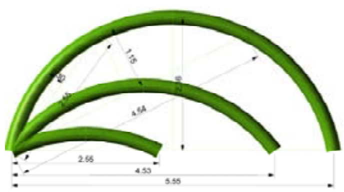


FIG. 3.51: STUDY ABOUT MODULARITY OF ARCHES

FIG. 3.55: TARPAULIN WITH REINFORCED BANDS

FIG. 3.52-54: STUDY OF COMBINATIONS OF ARCHES AND TARPAULINS

FIG. 3.56: STUDY ABOUT DIVISION OF THE INFLATABLE ARCH INTO SHORTER SEGMENTS

Through this analysis, the idea of dividing the arch into smaller segments arose. These segments are related to sub modules linked to the length of tarpaulin, for example when it is cut into two (three meters) or four parts (four meters). In this scenario, the inflatable arch is divided into shorter fragments that are combined using Tensairity® struts as presented in figure 3.56. This approach optimizes the length of the arch according to each particular case and can potentially speed up production, however drawbacks arise in the assembly phase but also as weaknesses in the connections. This is why this path was not investigated further in this dissertation.

3.2.5. Innovations of *ARK* and "component-based designs"

To summarize, the innovations of *ARK* can be grouped into three main categories according to three different levels: the process, the product and the component.

IMPLEMENTABLE

At the process level, *ARK* focuses on the opportunity to use the structure over time. With the aim of covering the "blank areas" of an intervention where a more structured sheltering programme cannot be addressed (due to the particular location, the uncertainties and the unknown requirements), *ARK* supports victims when repairing their dwellings and, at the same time, in combination with tarpaulin distribution, can offer a decent shelter for the very first days.

In addition, *ARK* structures can be arranged to be self-equilibrated and can therefore strongly contribute to the correct installation of tarpaulins or can even be used as a supporting structure for any kind of cladding component.

At a second stage, the system can be implemented and progressively substituted by local materials. For this reason, *ARK* is meant to bridge the gap between the emergency and developmental phases, contributing towards a transitional settlement approach.

ADAPTABLE

At the product level, adaptability is the main feature: as an alternative to "closed products", starting from a series of *ARKs,* several solutions can be arranged based on different layouts, addressing the predefined requirements but also matching the environmental and cultural background of the area of intervention. These products differ from the standard ones due to the possibility of disassembling each component (the ARKs, the cladding canvas, etc.) and re-arranging them into new configurations, if required.

FLEXIBLE

From a component point of view, *ARK* focuses on a flexibility that goes beyond modularity: the design approach arises at the component level and therefore a wider range of configuration is possible. In addition, each component can be modified according to need and is designed to interface and interact with other elements such as the cladding system or reinforcements.

These characteristics derive from the shift in approach that aims to find a balance between the "KIT" and "all-in-one" systems (see Chapter Five): based on the design of a single structural component instead of a complete and all inclusive product, this approach allows the possibility of an "open and shared design" among practitioners and victims which can actively contribute to the sheltering process

SIMPLICITY- INFLATABLE- READY TO USE

OPENNESS - TENSAIRITY® - IMPLEMENTABLE

Simplicity and openness of the solution are demanded, with respective to inflatable technology and the Tensairity® principle. The former deals with ready to use solutions that can be applied from the very first hours, while the latter allows the continuous implementation and adaptation of the system (see Paragraph 6.4)

The design of such kinds of component requires a careful balance between the openness of the solution and the features required to address specific needs. As clearly emerged from the analysis in Part One, the idea of solving an emergency by using very specific tools (designed to address a particular occasion) is tricky for two reasons: on the one hand, the requirements are never known in advance and, on the other, needs evolve over time.

In short, the perfect shelter does not exist.

The risk of this approach is to come up with smart tools that have no clear applications. To avoid this risk the concept has been verified through a series of mock-ups and tests to thoroughly check the feasibility of the idea from different points of view such as the manufacturing process (and therefore the cost), the structural behaviour, the durability of the parts and the materials involved.

These four areas of investigation will be presented in the next chapter.

4 CONSTRUCTION AND PERFORMANCE

4.1. Manufacturing

To shape the concept presented in Chapter three into a feasible, effective and applicable solution, a large number of prototypes were designed, built and tested by the author especially in the last year of the research. All the prototypes were build directly at a 1:1 scale by the author or through support from the company Eurovinil S.p.A., the worldwide leader in low-pressure inflatable shelters for both military and emergency applications.

The construction of 1:1 prototypes was considered an essential part of the research because scale models can be tricky from several points of view.

- First of all also the properties of the materials need to be scaled down and this is particularly difficult to do with the kind of thin materials that characterize membrane structures.
- Secondly, stability is based on overpressure and forces in the structure depend on the radius size.
- Thirdly, the manufacture of small prototypes is, sometimes, especially in the case of tensile structure, more difficult than cutting, welding and sewing larger surfaces.

LEARNING FROM MANUFACTURING

From the manufacturing of prototypes one can immediately understand issues that go beyond structural performance. In fact, feasibility in terms of cost, for example, which is strictly related to the labour required for each piece, can be checked directly especially where the manufacturer is a company that produces hundreds of products a year and has direct control over the production chain.

In addition, the durability of the material (fabric, struts) and connections (e.g. welding or seam lines) can be assessed through basic tests, while all kinds of unpredictable phenomena – difficult to foresee – can arise.

The mounting phase can also be checked together with identification of the number of people required for the setting up of a structure.

In point of fact, on paper, figures such as the weight and dimensions might appear feasible and easy to handle while, in real life, for example in the case of adverse climate conditions, they can generate hurdles. The main concerns regarding these aspects are related to the number of people required to set up a system (included simple actions that may generate problems such as the unloading of the component from a truck.

The technology has been identified by taking all of these aspects into consideration and combining them with a deep investigation of the current situation, as explained in detail in Part I.

In any case, apart from the previous considerations, the three main technological aspects could not be defined beforehand, and therefore they have been identified "along the way" with the help of the first experiments and prototypes.

All of these aspects are presented in the paragraphs below.

4.1.1.Low and high pressure inflatable technologies

Among the inflatable technologies, and specifically, inflatable arches, low pressure and high pressure systems are currently available on the marked and both are in use in the field by several NGOs or governments.

LOW PRESSURE ARCHES

Low pressure inflatable elements are much more widespread due to their higher load bearing capacity, the easier inflation process and an affordable cost. On the other hand, high pressure tubes are also interesting thanks to the reduced obstruction, weight and volume when transported.

The first technology suffers one major drawback: i.e. the loss of pressure and subsequent weakening of the system linked mainly to temperature excursions (from night to day, for example) which requires daily checks and refilling or a constant monitoring system that compensates for loss of pressure (which means extra costs and connection to an electricity supply).

The problem of relying on structures that require continuous maintenance during the period of their deployment is a constant and only worsens the reputation of a construction system that actually has huge potential especially when logistics and speed are crucial. This is definitely the main reason why inflatable systems are not so common, either in permanent architecture or for emergencies. They remain successful in leisure applications or for very temporary occasions such as leisure or exhibition events.

HIGH PRESSURE ARCHES

The issue of deflation does not affect high pressure tubes but, on the contrary, the success of this technology is totally reliant on the inflation system (compressor). Doubts about the possibility of malfunctioning of these devices and difficulties in repairing them, make the diffusion of these technologies even more difficult and slow.

Experiments with high pressure tubes were carried out by the author during research into the integration of low pressure beams with high pressure tubes as the compression elements[1] where problems of maintaining high pressure constant had been identified previously.

OVERCOMING THE ISSUES

Based on these known issues, the Tensairity® principle might be an interesting alternative for application in emergency sheltering. The low pressure nature of the system makes inflation possible even by hand, also in the worst scenario of blower failures or electricity black-outs.

In addition, the Tensairity® compression elements once integrated into the system, may collaborate to the stability of the shelter even at very low pressure or when temperature fluctuations make the system weak. On the other hand, the Tensairity® principle can greatly improve the load bearing capacity of the whole system for example in the case of hurricanes or extra, unexpected loads, or more simply result in the distribution of slender components with a comparable load bearing capacity.

4.1.2. Single or double layer construction systems

The manufacturing methods of standard inflatable arches always face the trade-off between, on one hand, lightness, cost, time of manufacturing and on the other, air tightness. The lighter the material, the higher the probability the air will perspire from the fabric itself. This is why thick materials, with a generous amount of coating are used. Unfortunately, these materials are more expensive and add weight, with direct consequences on the final cost of the solution.

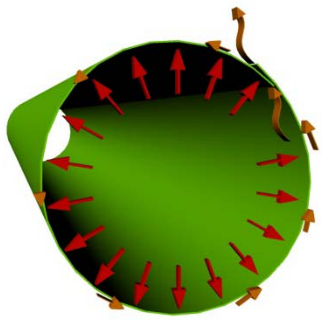


FIG. 4.1: AIR MAY ESCAPE FOLLOWING THE FIBRES

In addition, seam lines and valves are always weak points and are the places where leaks are. As will be presented in Paragraph 4.5.1, seam arrangement is crucial to ensure air tightness and to avoid the air escaping, for example, through fibres. however, sometimes correct seam arrangement is difficult and can slow the production process, thereby affecting cost.

CONSTANT BLOWING OF AIR

There are two alternatives to solve this issue. On the one hand, there are structures supported by the constant blowing of air: in this case, a very light textile material (to reduce the cost) and even stitching connections (to speed up the manufacturing process) are possible. In this case, the cost of manufacturing drops but so does the structural efficiency and the continuous blowing of air, which requires electricity, is possible only in very temporary events and definitely not welcome in emergencies.

INNER BLADDER

Alternatively, there are double layer inflatable systems. These kinds of inflatable structures are usually made of polyester or another high tenacity fabric on the outside (stitched or welded) with the aim of withstanding the tensile stresses, with a film bladder made out of PU (polyurethane) or PE (polyethylene) in the inside, which ensures the air tightness of the hull. Films are easier to manufacture, faster to repair and maintain the pressure better than coated fabrics. In addition, internal bladders can be substituted at low

[1] Maffei R. (2009), *Innovative lightweight structures: water and membranes*, Master thesis, Politecnico di Milano

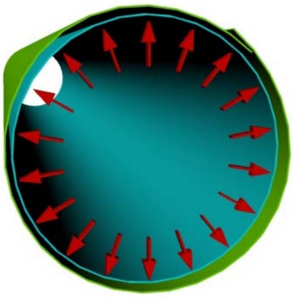


FIG. 4.2: DOUBLE LAYER SYSTEM

cost in the case of damage, and this is definitely an advantage compared to mono-layer systems which, in the case of failure, need to be completely substituted. The total weight of the second solution is several times lighter than the first, even if the square metres of the material is double.

In emergency applications, the first option is not feasible while the second looks more promising, both in terms of cost and maintenance.

4.1.3. Different Tensairity® configurations

The Tensairity® principle has been widely investigated in linear beam configurations while research into arches is only beginning. Structural optimization of the Tensairity® arch is not the goal of this dissertation and interesting researches in this direction have already been carried out[23]. Optimization of the load bearing structure cannot be carried out from an engineering point of view only: for this reason, the span/height ratio cannot be the main driver in emergency applications. In fact, in sheltering, structural performance is rarely pushed to the limits as happens, for example, in bridges or large span roof covers. Other factors more strongly influence the definition of the final shape: usability of the space being definitely the most important one.

In fact, the final shape of a shelter mainly derives from the dimensions of the human body and the lifestyle of the affected community. Family shelters distributed in third world countries, for example, are characterized by a low ceiling to ensure a small enclosed space (which is easier to heat) but also because people inside their dwelling are used to sitting on the floor. In the case of collective shelters, on the contrary, the standard span is around five meters which derives from the sum of the length of two beds (2 metres each) and a corridor in between (1 metre) to ensure the minimum amount of space for a hospital configuration. Height is mainly defined by the possibility of using the majority of the ground surface without having to stoop. At the sides, therefore, the walls must be as vertical as possible even if a special arrangement of furniture could allow the lowering of the ceiling without space loss.

From all these consideration, it is clear that the identification of the contribution of the Tensairity® principle in sheltering, passes through adaptation to the shape which characterizes the state of the art, without focusing on an optimal shape that will probably never be applied.

Between a family and collective shelter, this thesis mainly focuses on the second category even if, as presented in paragraph 3.24, the modularity of the concept might be easily adapted to smaller sizes. The size of prototypes suitable for a collective shelter can be handled by one single person and manufacturing does not require special machinery.

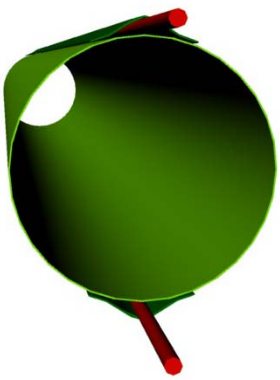


FIG. 4.3: TENSAIRITY® "O" VERSION

2 Crettol R., Gauthier L. P., Luchsinger R. H. Vogler R, (2010), *Tensairity Arches*, Proceedings of the International Association for Shell and Spatial Structures (IASS) Symposium 2010, Shanghai

3 Roekens J., Mollaert M. De Laet L. Luchsinger R. H. (2011) *Preliminary investigation to Tensairity arches*, International Conference on Textile Composites and Inflatable Structures Structural Membranes 2011, Barcelona

The state of the art of inflatable emergency shelters mainly shows segmented arches which are easier and cheaper to produce. Even if the feeling, both from theory and experience, is that the Tensairity® principle works better with smooth shapes, it is considered worth investigating whether it would contribute positively also in segmented arches, thanks to specific angular joints able to connect the linear struts.

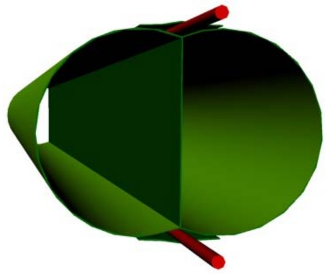


FIG. 4.4: TENSAIRITY® "WEB" VERSION

In addition, the latest Tensairity® development has produced a "web" version, where a vertical membrane that connects the upper and lower rods is pre-stressed by the inflation and positively improves the rigidity of the system. Standard "O" section Tensairity® beams, on the other hand, are much easier to manufacture and present the same ultimate load bearing capacity. Both versions are worth an investigation as shown in the definition of the mock-ups in the next paragraph.

4.2. Preliminary structural investigations

From a geometrical point of view, there are endless possibilities to shelter a 5m span with an average height of 2.2m as demanded by the humanitarian sector. Inflatable systems can easily be produced already segmented, in a way that approximates the final, smooth shape which can also be produced but requires much more time in terms of production and a careful design and cutting pattern. In fact, production methods are mainly based on the transformation of flat fabrics into 3D forms through a process of cutting and welding/sewing. This point will be presented in more detail in Paragraph 4.6.1.

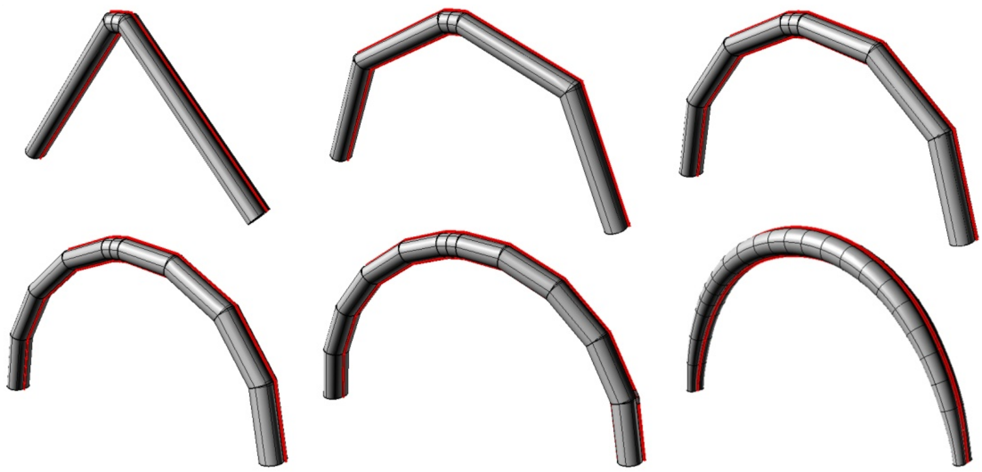


FIG. 4.5: STUDY OF TENSAIRITY® ARCH TYPOLOGIES

The results of a comparative test campaign are presented in the following pages together with an analysis of the manufacturing process, assembly steps and deployment in the field. Special attention has been dedicated to packaging and transportation issues which are crucial in both military and humanitarian applications.

The results of this investigation aim to focus on the main drawbacks of standard inflatable structures but also to push inflatable technology beyond its current limits, for

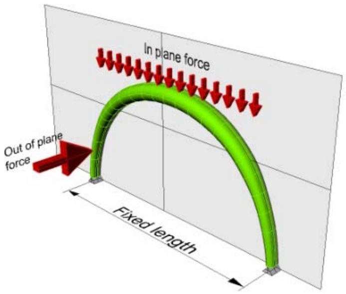


FIG. 4.6: IN PLANE AND OUT OF PLANE FORCES ACTING ON AN ARCH

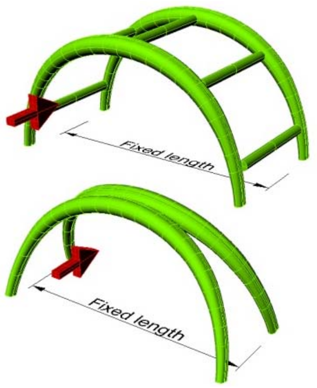


FIG. 4.7: STABLE CONFIGURATIONS AGAINST OUT OF PLANE FORCES

example, by entering the range of large span structure like hangars or warehouses which, at the moment, are mainly based on metal frames and require large shipments and machinery at the construction site.

4.2.1. Stability of arch-based systems

The stability of arch-based construction systems is simple in the arch plane: as long as the two end parts are bound and horizontal displacement is avoided, the arch behaves correctly. On the other hand, out of plane forces can easily make this structural system unstable and therefore several arches need to be connected to counterbalance these forces.

This is why the stability of one single arch is not an easy task. The simplest solution is stabilization through guy ropes or cladding as presented in figures 4.8-9. In the case of a combination with existing structures, such as walls or other parts of dwellings, stabilization becomes much easier and a recovery shelter can rapidly be set up.

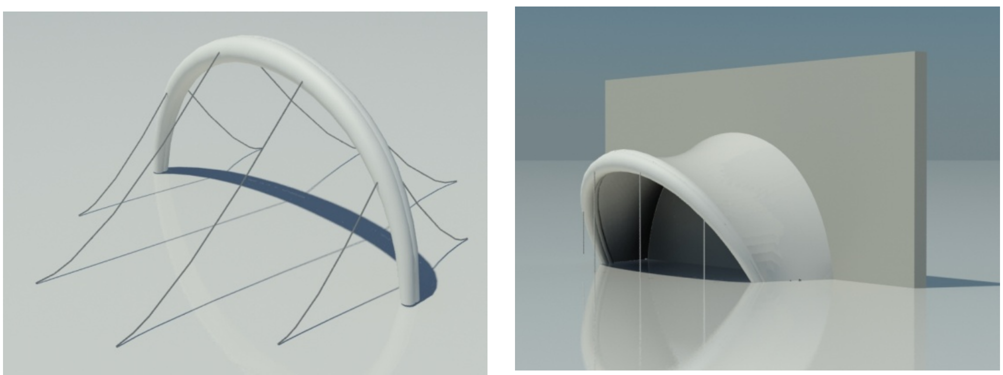


FIG. 4.8-9: SINGLE ARCH CONFIGURATION: STABILIZATION BY CABLES OR AGAINST A WALL

When arches are distributed in pairs, the number of possible configurations increases greatly and, following the stabilization strategies seen above for a single arch, a self equilibrated shelter can easily be arranged. In addition, if two arches are placed one close to another and connected in such a way that they work together, they generate a momentum able to withstand external loads. Of course, anchoring and connection to the ground must be provided in any case, to avoid the whole structure blowing away due to the wind.

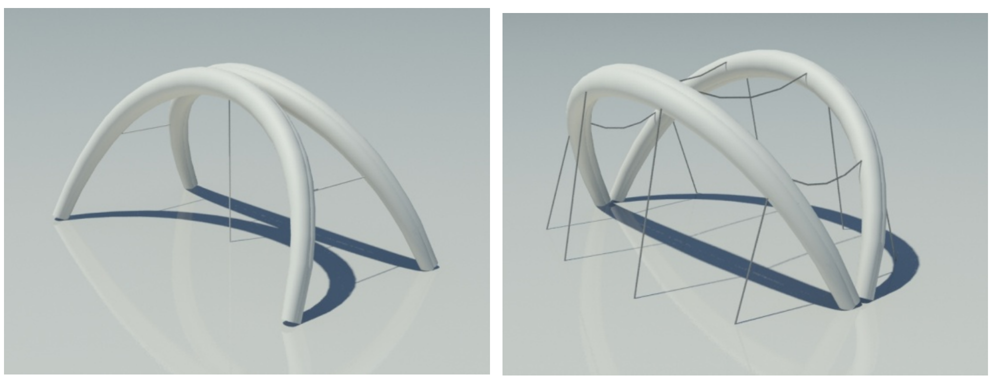


FIG. 4.10-11: TWO ARK CONFIGURATIONS STABILIZED BY CABLES: "A SHELTER" AND "V SHELTER"

Starting from the "A" and "V" shelter layouts (shown in pictures 4.10 and 4.11), the stability of the system can be ensured by the tensioning of cladding system together with compression struts as displayed in picture 4.12). In this case, external shaded areas are easily provided but, to guarantee the correct tensioning of the whole surface and therefore to prevent pounding or flapping, the cladding must be a double curvature layer and therefore, cannot be made with simple, flat tarpaulin. In that case, this component can easily be distributed within the kit.

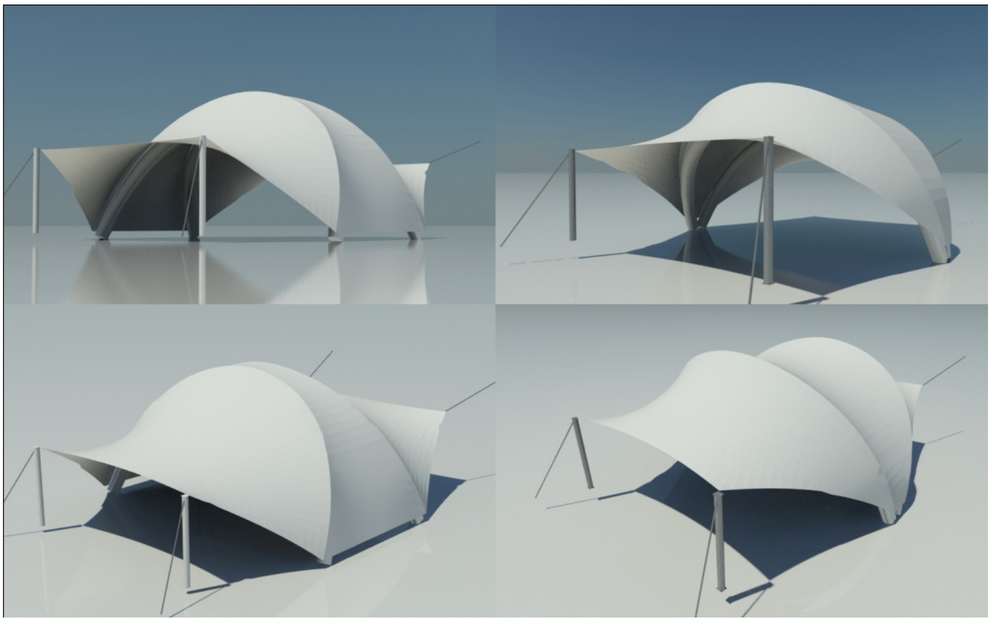


FIG. 4.12: TWO ARKS CONFIGURATION STABILIZED BY CLADDING

When more than two arches are distributed, we enter the range of collective or service sheltering infrastructures which are most likely to be set up by practitioners. In this case, the arrangements of the shelter may vary as presented in figures 4.13-14 and 4.15. Among all these options, it is difficult to identify in advance the most suitable layout. On the contrary, this choice needs to be made in collaboration with local actors, practitioners and – why not – the local population too, by implementing the screening of mapping, and taking the cultural background and construction traditions into account too.

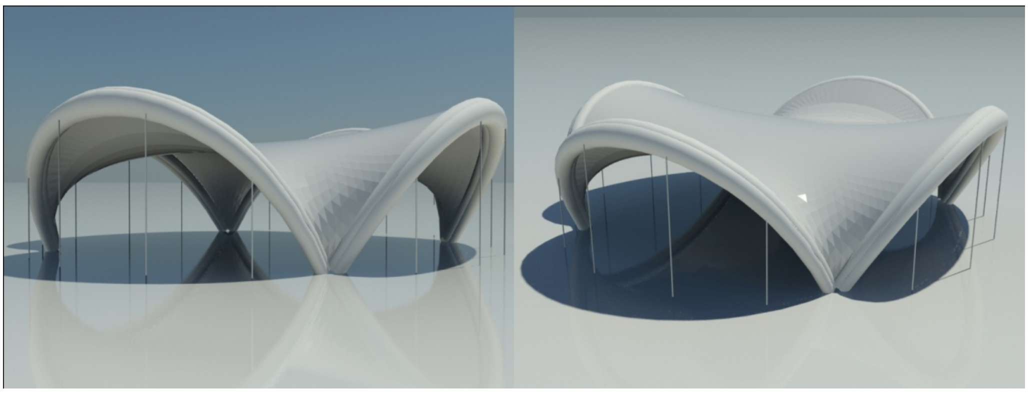


FIG. 4.13-14: FOUR ARKS CONFIGURATION STABILIZED BY CLADDING

In the case of the distribution and application of ARKs as a structural component of a standard shelter product, the complexity of the system increases and therefore stability cannot be assured by tension only. A solution for the problem of stabilization is the integration within the kit of inflatable or rigid struts. In this cases, the structural system becomes more traditional and offers the possibility to create air frames which are closed and self-equilibrated. As presented in figure 4.15, straight or even curved tunnels are the most common layout in this category.

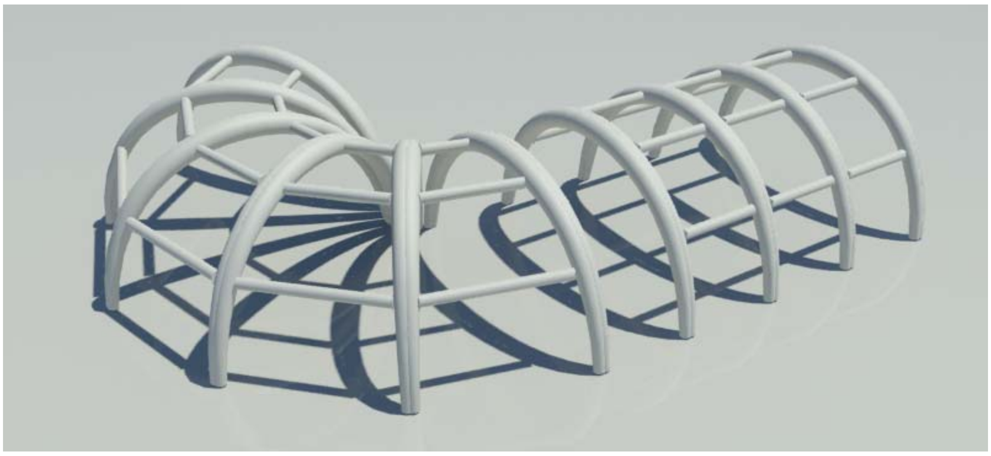


FIG. 4.15: ARKS AS PART OF COLLECTIVE SHELTERS OR OTHER INFRASTRUCTURES

4.3. Prototypes

Several prototypes were built during the three years of research and can be divided into four macro areas: 1) linear elements, 2) segmented arches 3) smooth arches 4) double layer systems (either linear or curved elements). In the following paragraphs, the design process, the form finding calculation, the cutting pattern generation, the seam lines arrangements and the construction methods of the most interesting experiments are presented.

4.3.1. Linear beams

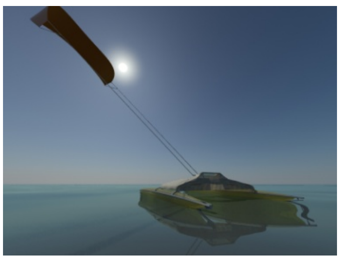


FIG. 4.16: CATAMARAN "KITE-KAT"

Several prototypes of linear, "O-section" elements were built mainly to learn how to control and shape inflatable structures and how to manufacture them in an efficient way (in relation to time, cost and durability). The application of these prototypes was the design of an inflatable catamaran powered by the flight of a kite, named "Kite cat". The advantages of an inflatable solution instead of a rigid hull range from a saving in costs and to the possibility of easy transportation.

FIG. 4.17-18: FIRST DESIGN OF THE INFLATED CATAMARAN

The form finding generation of asymmetric hulls was generated following the cross section approach presented in Part II, Chapter 3.1. The section became thicker in the area where the seat is located to better support the load of the driver and the forces coming from the Kite. In fact, the kite is not attached to the catamaran but only to the driver which sits on it.

The cutting pattern was based on a pair of panels to ensure the air-tightness of the structure (see paragraph 4.5.1). Three reinforcement struts were designed: two on the upper side to connect the seat and one in the lower part to withstand the water pressure. Several 1:5 and 1:2 models were manufactured to come up with the final design. Some of these are displayed in picture 3.4 and 3.5. The final design is presented in pictures 4.19-20.

FIG. 4.19-20: 3D VIEWS OF THE TENSAIRITY® HULLS

The final cutting pattern is displayed below: the panels are symmetrical and present a higher curvature where the hull becomes bigger (the rear). The end caps were welded on with a circular electrode and due to their small radius, this was the most difficult phase of the manufacturing.

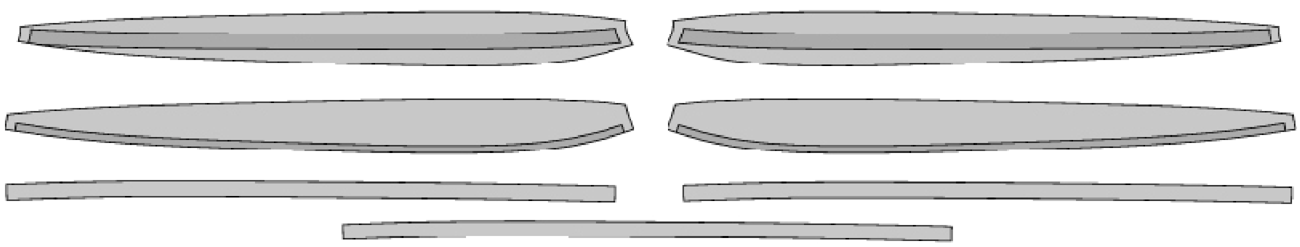


FIG. 4.21: CUTTING PATTERN ASYMMETRIC HULL

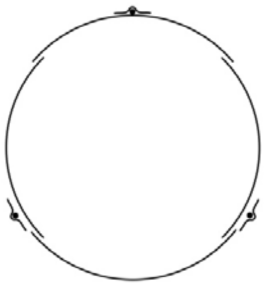


FIG. 4.22: "O SECTION" HULL OF THE CATAMARAN

The manufacturing, the assembly of the hulls, the metallic frame and the steering system were all done by the author himself. The designing was done parametrically and therefore any change in shape or dimension could be applied in a matter of minutes. At any rate, each hull required around 20 hours of work, from the drawing of the panels, to the cutting of the parts and the welding of all of them. Problems arose with the air-tightness of the system. A special glue was used to seal the leak points, especially in the end-cap areas.

FIG. 4.23: FULL PROTOTYPE

"O section" Tensairity® was used for the catamaran's hulls for hydrodynamic reasons. The section is displayed in picture 4.22.

A Tensairity® web structure was manufactured in a second stage. This simple two-metre long mock-up was used to test seam lines due to the complex manufacturing of the web.

FIG. 4.24-25: LINEAR BEAMS: STANDARD "O SECTION" (GREY) AND TENSAIRITY® WEB VERSION (BLACK)

As displayed in the pictures below, two seam arrangements were investigated.

Fig. 4.24-25: Seam arrangements for the manufacturing of the Tensairity® "web" version

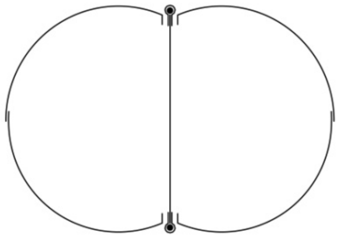


Fig. 4.26: Extra welding on the hull

On the left hand side, a pocket designed to host the reinforcement strut is welded to the top of the hull, in the area where the web is under tension. In this case, when buckling arises, the forces are transferred from the struts to the pockets and then to the whole hull, without direct interaction with the pre-stressed web.

On the right hand side, on the contrary, the strut is tightly connected to the vertical membrane through a pocket which is welded onto it directly. At a second stage, the two sides of the hull are welded to the web.

Fig. 4.27: Linear Tensairity with web

Fig. 4.28: Connection upper strut and lower cable

Several comparison tests were carried out to prove the efficiency of the system.

Tensairity® beam, (left) 2.2 meters span carried 120 kg.

Without Tensairity® (right) the span of the same air beam was reduced by up to 1.8 metres and the system became unstable at 60 kg.

Fig. 4.29: Comparative tests of the linear beam, with (left) and without (right) Tensairity®

Even if the second case is probably more efficient, problems with manufacturing arise: first of all, the structure can only be welded in that way if the two hulls present an additional seam line as shown in picture 4.26, otherwise the welders cannot reach the seam; secondly, the system may undergo peeling, as will be presented later in the arch prototype; thirdly, the five layers need to be welded one on top of the others which may be risky in terms of accurate welding.

For all these reasons, the left hand option has been identified as the most promising in terms of manufacturing and, if dimensioned correctly, the transfer of force to the struts which cannot move or buckle within the pocket, is probably as effective as the other one.

4.3.2. Segmented arches

Starting from current inflatable shelters in use in Western countries, a segmented, O-section arch was manufactured by Eurovinil S.p.A. This arch is the one currently on the market and included in the commercial inflatable tent Tag-NG. The tested arch was used for several months in the base camp around L'Aquila after the earthquake of 2009.

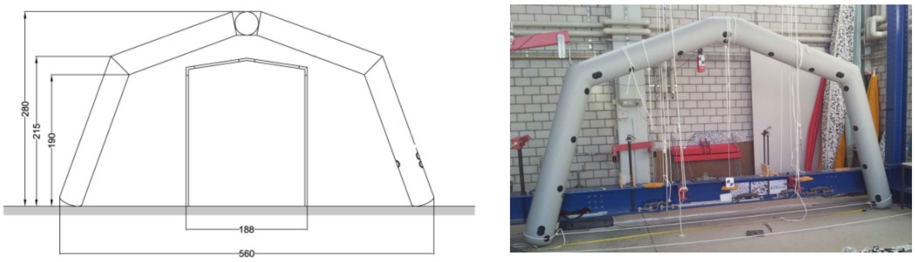


FIG. 4.30-31: STANDARD SEGMENTED ARCH OF TAG-NG

The dimensions of the arch are the following:

Span: (external): 5.6m
Central height (external): 2.8 m
Site height (external): 2.15 m
Tubular radius: 0.175 m

The cutting pattern for the segmented arch is relatively simple and as shown in picture 4.32.

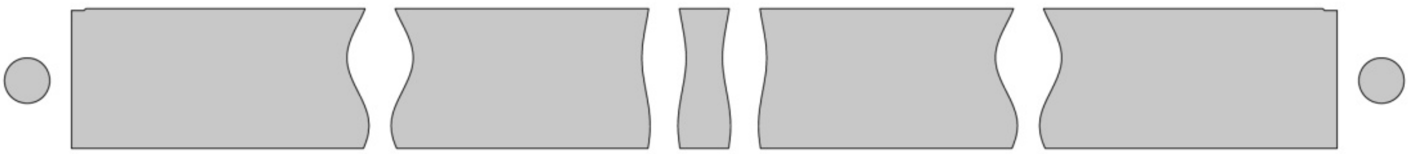


FIG. 4-32: CUTTING PATTERN OF A STANDARD SEGMENTED INFLATABLE ARCH

Thanks to the standardization of the process (electrodes dedicated to each panel and ready to weld the valves and connection all at the same time) plus optimization of the components (the fabric width corresponds to the circumference of the tubes, therefore the cutting pattern is only in the cross direction), the manufacturing of a standard arch in the factory is really efficient and takes about half a day.

An evolution of the segmented arch is presented in pictures 4.34 and 4.35 without any particular adjustments to the standard layout. Two pockets are welded from the internal side of the hull to host the reinforcement to turn the inflatable arch into a Tensairity® one.

The pockets are welded this way to maximize their efficiency at the moment of buckling in such a way that the struts would push onto the continuous surface of the hull instead of simply pushing on the pockets with the risk of tearing them off.

The dimensions are the same as the standard segmented arch presented above.

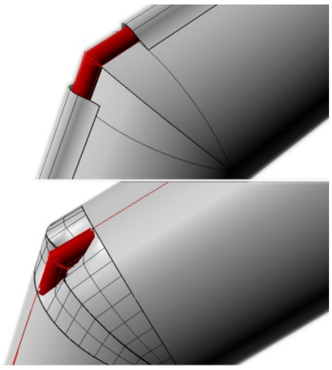


FIG. 4.33: EXTERNAL (UP) AND INTERNAL (DOWN) POCKET

FIG. 4.34-35: TENSAIRITY SEGMENTED ARCH: DESIGN AND PROTOTYPE

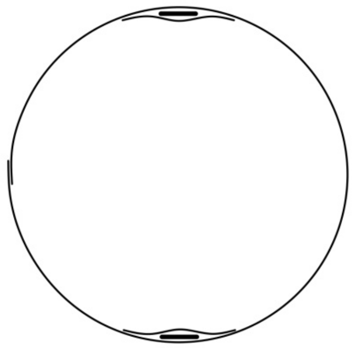


FIG. 4.36: "O SECTION" OF THE SEGMENTED TENSAIRITY® ARCH

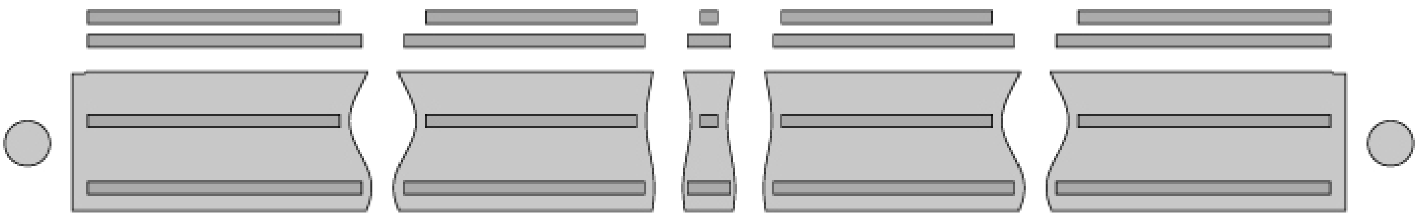


FIG. 4.37: CUTTING PATTERN OF A TENSAIRITY® SEGMENTED ARCH

The struts are linear aluminium plates connected together through pre-bent steel plates. These struts are connected at their ends through a wooden block cut at the right angle to support the arch.

FIG. 4.38-39-40: CONNECTION OF THE STRUTS IN THE TENSAIRITY® SEGMENTED INFLATABLE ARCH

4.3.3. The smooth arches

The third category of prototype is a smooth arch. A Tensairity® smooth arch, with a web based on the dimension of the standard arch was designed and manufactured at Eurovinil S.p.A. The welding phase was complex and time consuming (almost 4 times more than the standard one). The first cutting pattern adopted is illustrated in picture 4.44 and the section is shown on the right. Unfortunately, unexpected peeling forces arose in the area of the struts as shown in scheme 4.44, especially in the central part of the arch (where the section is bigger and therefore the tangential tension becomes perpendicular to the web) As a result, after one day of inflation, the longitudinal weld was completely torn apart as shown in pictures 4.45,46 Three different arches of this kind were designed and manufactured before finding the right welding arrangement to avoid peeling when high stresses are introduced into the system.

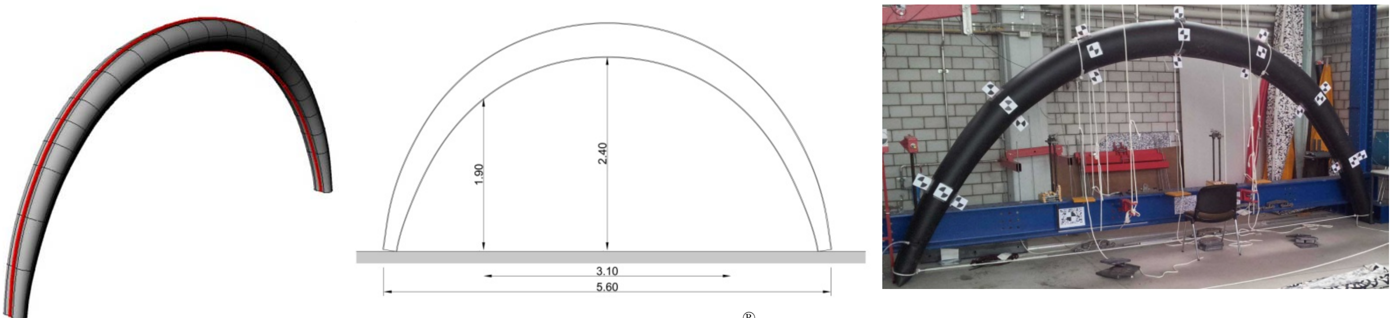


FIG. 4.41-42-43: SMOOTH TENSAIRITY® ARCH: DESIGN, DIMENSIONS AND PROTOTYPE

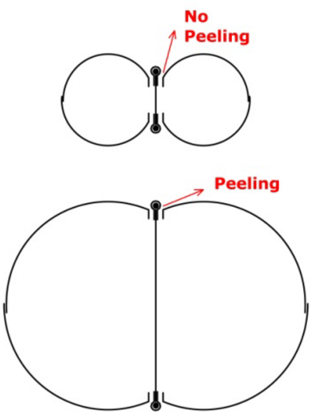
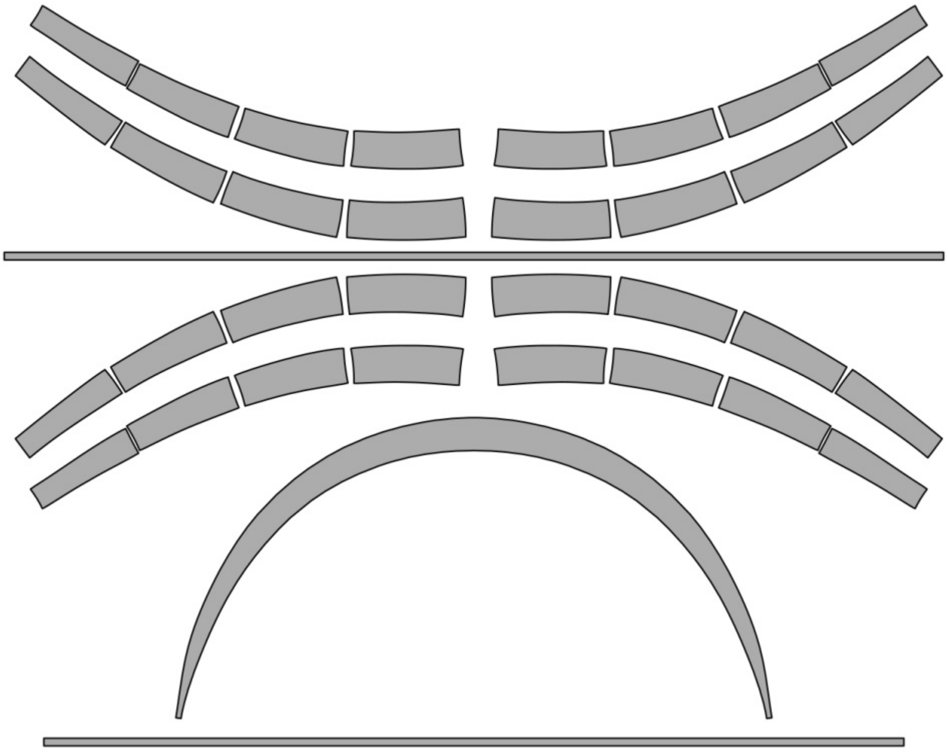


FIG. 4.44: PEELING PROBLEMS: END SECTION (TOP) AND CENTRAL SECTION (BELOW)

FIG. 4.45-46: DAMAGES DUE TO PEELING AFTER ONLY ONE DAY OF INFLATION



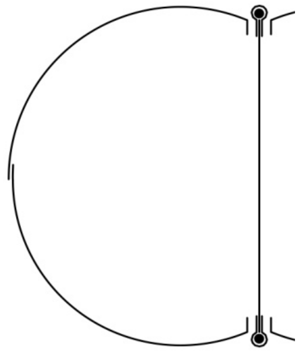


FIG. 4.48: WELDING ARRANGEMENT OF THE SMOOTH TENSAIRITY ARCH

FIG. 4.47: SMOOTH TENSAIRITY® ARCH: FIRST CUTTING PATTERN

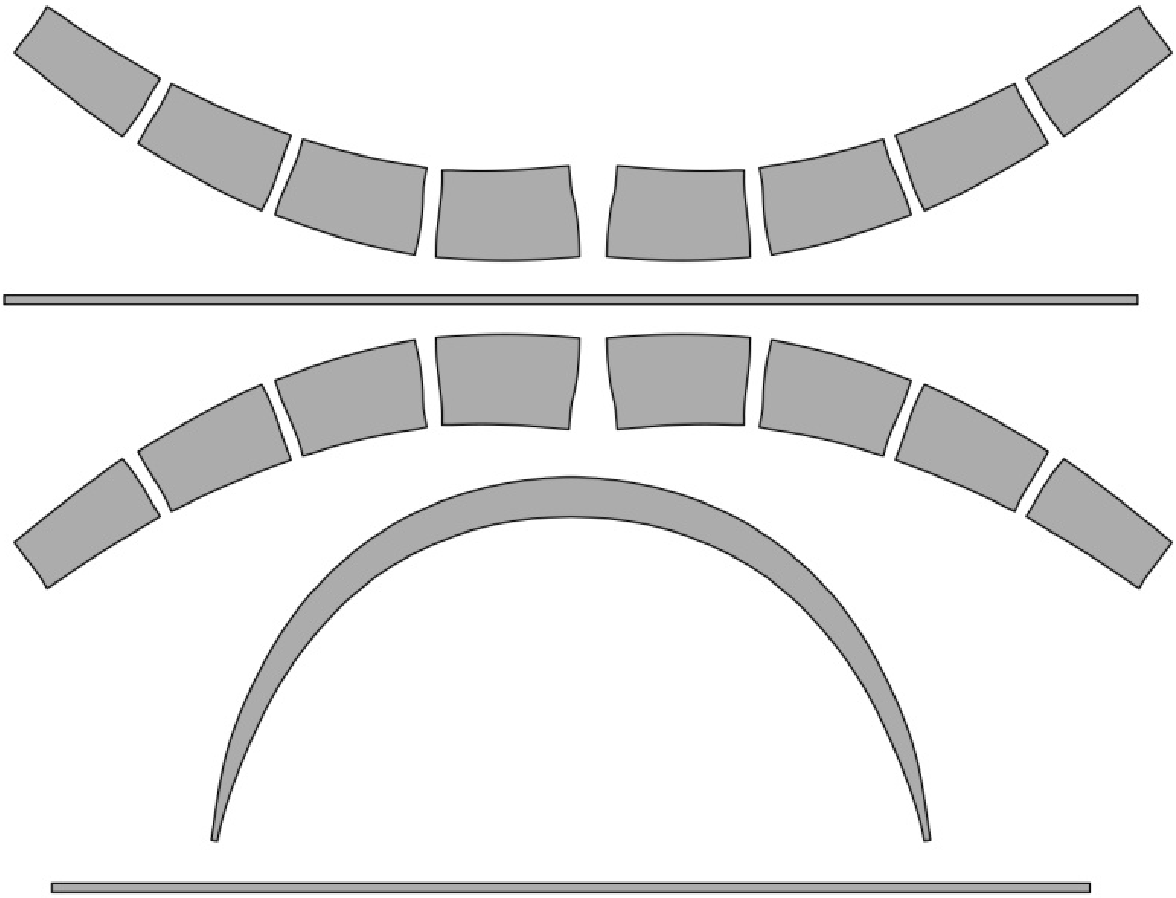


FIG. 4.49: FINAL CUTTING PATTERN FOR THE SMOOTH TENSAIRITY® ARCH WITH WEB

Finally, a simplified version was manufactured using the pockets as reinforcement to prevent the peeling as shown in picture 2.24. As for the linear elements, the transfer of load is probably not optimal, but the advantages in terms of construction and durability are much higher. Moreover, thanks to this arrangements of seams, each semi-hull does not need to be divided in two, therefore 16 panels are enough to create the desired smooth curved shape compared to the 32 parts of the cutting pattern shown in 3.43.

4.3.4. Double layer systems

Double layer systems involve separating the structural and air-tightness functions by means of two different layers. As presented in paragraph 4.1.2, the internal layer is usually a film (which is easier to manufacture, and is lightweight, and airtight) welded at high frequency; on the contrary, the external one is a high strength fabric (coated or not) which can even be sewn (and is therefore much easier to process). In any event, the smooth arch shape investigated in the previous paragraph needs a careful geometrical analysis in terms of cutting patterns which present curved lines.

An alternative to the complex cutting and sewing work is to assemble the two semi-hulls through a double keder profile either in metallic or plastic material (picture 4.55). The advantage of this solution is the fact that the hull is simply defined by the semi-hulls which do not need to be welded through a curved seam. Moreover, the keder profile would act as a reinforcement strut too. The cutting pattern presented in picture 4.54 derives from a segmented arch where each segment is conical (while in picture 4.30 it was cylindrical) and therefore all panels are developable surfaces (their surfaces are curved only in one direction).

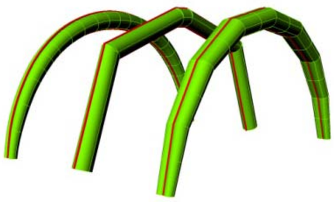


FIG. 4.50: FRONT ARCH AS COMPROMISE BETWEEN THE TWO AT THE BACK

This example is, therefore, a compromise between the smooth shaped arch of the previous section and the four-segment case of paragraph 4.2.1. Of course, in this case, the construction system is not airtight but requires a second layer: the outer one is joined by the keder profiles while the internal film is independent.

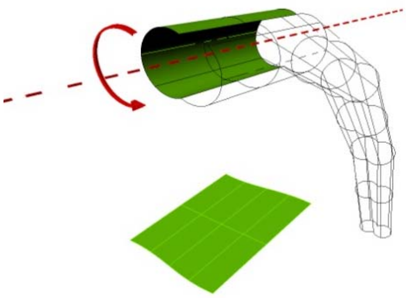


FIG. 4.51: CONICAL DEVELOPABLE SURFACES

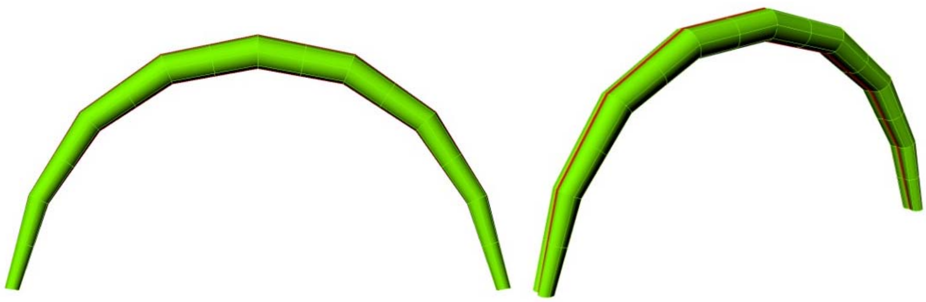


FIG. 4.52-53: TENSAIRITY® ARCH WITH WEB BASED OF DEVELOPABLE SURFACES

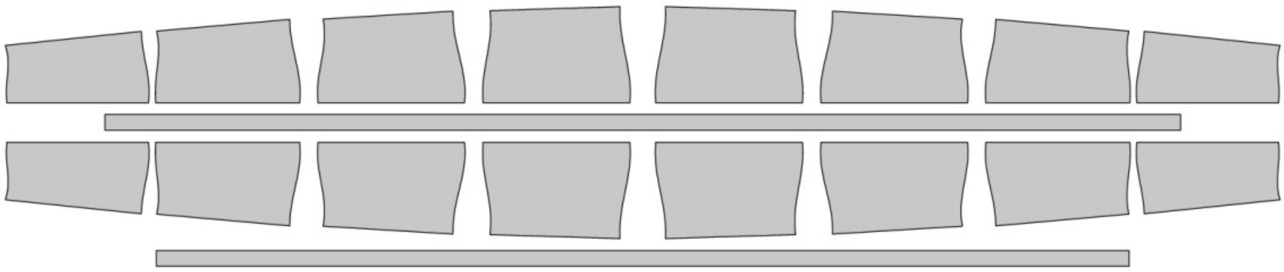


FIG. 4.54: CUTTING PATTERN FOR THE DOUBLE MEMBRANE SEGMENTED ARCH CONNECTED THROUGH DOUBLE KEDER PROFILES

Keder can be double or even triple with the possibility of connecting a vertical web too as shown in pictures 4.55 and 4.56. According to the dimension, material and thickness of these components, the structural capacity of the system varies. Examples of commercial profiles of this kind are displayed in picture 4.57, either in PVC or aluminium with different structural properties.

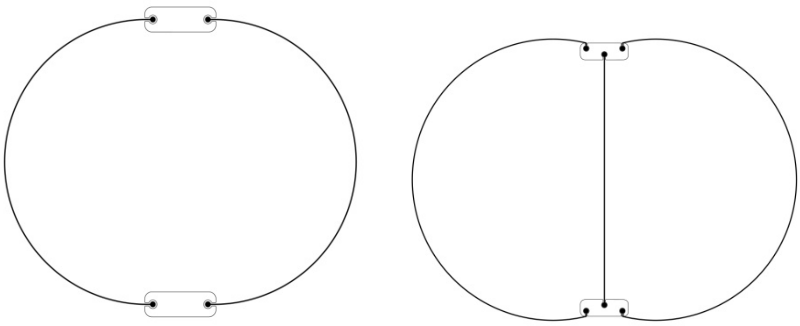


FIG. 4.55-56: SECTION OF TENSAIRITY® DEVELOPABLE SYSTEM CONNECTED WITH KEDER PROFILES

FIG. 4.57: PLASTIC AND ALUMINIUM DOUBLE KEDER PROFILE AVAILABLE ON THE MARKET

Another advantage of producing a double layer system is the possibility to sew on the external fabric, and therefore, to generate a much more precise shape avoiding the limitations that derive from the linear electrodes used for welding. In this case a keder profile to connect the panels is not required and therefore the system can either work with or without reinforcements, which can be inserted into pockets only if/when needed.

4.4. Structural behaviour

Some of the abovementioned prototypes underwent a loading campaign to investigate the effectiveness of the technology and the benefits of the application of such innovative principles.

Due to the complex geometry of the elements in analysis and due to the large number of variables which affect their structural efficiency, this author found difficulties to homogenize the inputs and to come up with meaningful general data. Therefore, the following results should be considered merely as a preliminary investigation and a comparative analysis.

The following chart summarizes the characteristics of the manufactured prototypes.

Prototype	Typology	Construction	Section	Geometry	Span	Reinforcement geometry (mm)
1	Linear	Mono layer	“O” section, three struts	Cigar	2.2	Cylindrical profiles Ø 6
2	Linear	Mono layer	Web section, two struts	Cigar	2.2	Rectangular profiles 15*6
3	Arch	Mono layer	“O” section	Segmented	5.6	Rectangular profiles 40*6
4	Arch	Mono layer	“O” section	Segmented	5.6	Rectangular profiles 40*6
5a	Arch	Mono layer	Web section, two struts	Smooth	6.4	Not present
5b	Arch	Mono layer	Web section, two struts	Smooth	6.4	Cylindrical profiles Ø 6 and rectangular profile 15*6
6	Arch	Double layer	Web section, two struts	Segmented	5.6	Rectangular profiles 40*6
7	Linear	Double layer	“O” section	Cigar	1.8	Two double keder profiles

As shown in the chart, a straightforward comparison between the prototypes is difficult to do. Looking at the linear elements (1 and 2), even if the span is the same, the reinforcement struts are different (three struts in “O” Tensairity® and two struts in the web version), influencing the structural behaviour of the elements. On the other hand, the arches (3-6) differ greatly in span, section and size of the reinforcements.

Even if one of the structural goals of this dissertation was to identify an optimal geometry by comparing smooth and segmented structures, this task could not be fully achieved with the prototypes and tests done by the time this dissertation was written. In fact, unfortunately, due to unpredictable factors mainly related to the manufacturing phases, at the end of inflation, the prototype did not present the expected span but a much larger one.

FIG. 4.58: THE DIFFERENCE OF SPAN OF THE TWO PROTOTYPES.

The reasons for the difference are various. First of all, the geometrical assembly differs greatly: in the segmented arch, the fabric is stressed constantly along its section due to the alignment of the warp and weft directions and the constant radius, while in the smooth case, the radius and fibre orientation varies along the length of the arch. For this reason, the biaxial stress pattern differs, creating deformation in the longitudinal direction. In addition, the manufacturing process strongly influences the final shape. In fact, the seam lines are composed of 3-4 or even 5 layers welded one on the top of the other, thereby stiffening the edges of the panels and deforming the material which elongates in these parts due to the high frequency welding process. In this way, the seams became less deformable than the fabric itself. As a consequence, the arch is somewhat stretched longitudinally, modifying the height/span ratio of the arch which becomes more linear and, therefore, longer than the expected size.

For this reason, a comparison between smooth (prototype number 5) and segmented configurations (prototype 3 and 4) cannot be accurate and therefore the data shown in paragraph 4.4.3 must be read critically.

4.4.1. Physical test

Three arches were tested more than others: two versions of the segmented arch (numbers 3 and 4) and the smooth arch with web (number 5).

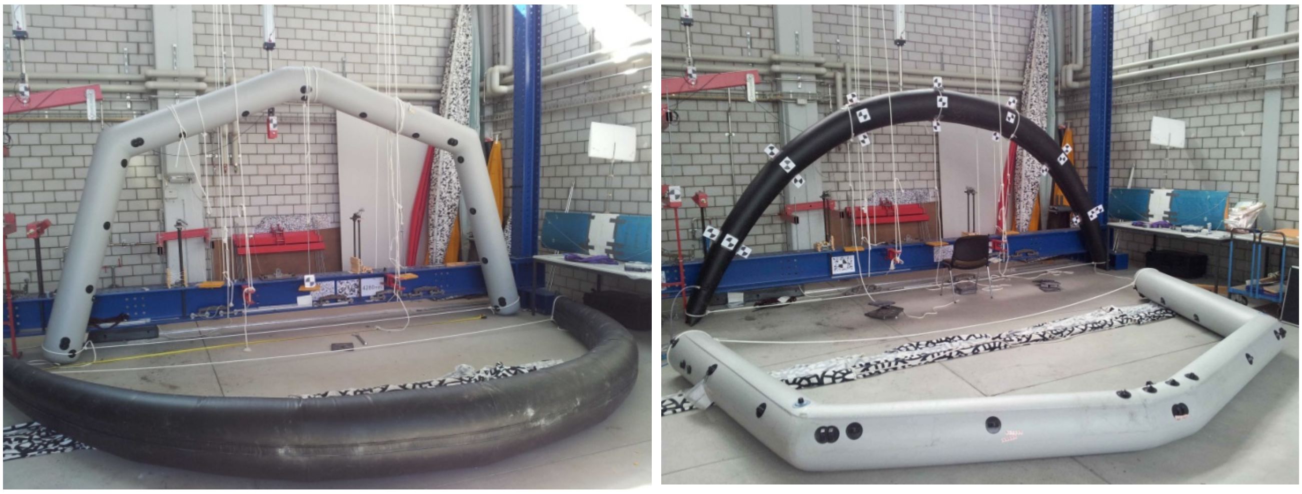


FIG. 4.59-60: TESTS SET UP

The main issue of the loading was the generation of out-of-plane forces. Consequently, a set-up was arranged to prevent these forces: the arches were kept in place by four cables (two at the front and two at the rear) which ran from the ceiling to the floor.

FIG. 4.61-63: ANCHORING ENDS FOR SEGMENTED AND SMOOTH ARCHES

The foundation was created using wooden blocks to which the reinforcement struts were screwed. In the case of reinforcements based on rods, metallic end parts were designed accordingly as shown in picture 4.61.

Both wooden and metallic foundation systems have two main functions: the first is, of course, the transfer of load from the arch to the floor and the second, more important, the transfer of forces between the upper and lower struts as required for the Tensairity® principle to behave effectively.

The end points of the arch were connected together at a fixed length (the desired span) by a rope to prevent the ends sliding in the X direction.

Loading was done manually in steps of 10kg per point load. Three or five points of load were used for different tests trying to simulate the distributed load which comes, for example, from cladding pushed by wind pressure. The point load was also taken into account, simulating the connection of local loads (such as clothes or technical devices).

Overpressure of the arches during loading was kept constant at two different pressure levels: 200 and 300 millibars. The latter value is standard for similar systems available on the market, while the first was selected to investigate the behaviour of Tensairity® at very low pressure, for example, in the case of loss of air or temperature variation, to make sure it can be easily reached with a manual pump.

4.4.2. Numerical analysis

Numerical analyses were carried out through final element calculation in Abaqus[4].

Materials were modelled using a linear elastic isotropic with E=500MPa and ν=0.3. the direction of the fibre of the fabric was modelled as in the manufacturing. In the case of the Tensairity® principle, the struts were modelled tightly connected to the hull over their total length assuming that the friction force within the pockets does not allow any relative shift, also at the moment of loading – which is reasonable.

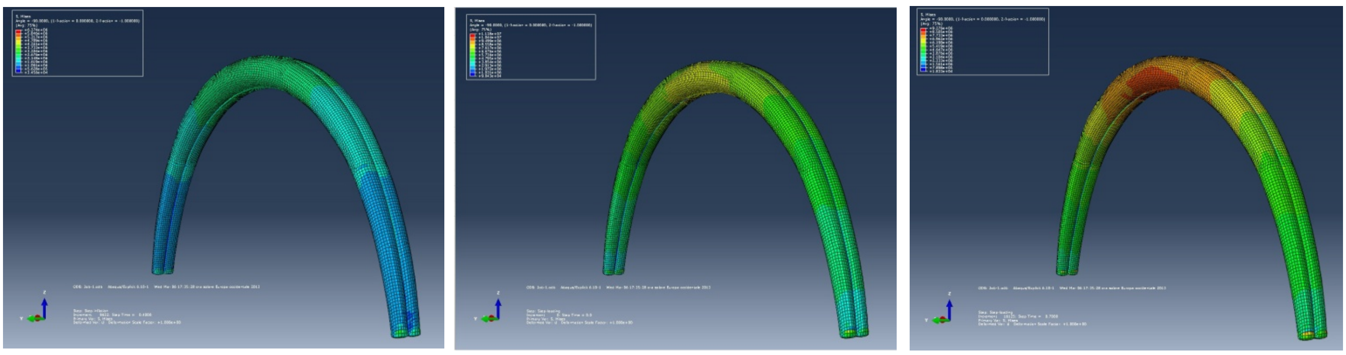


FIG. 4.64-66: LOADING STEPS: BEGINNING OF INFLATION, END OF INFLATION AND END OF LOADING

[4] Constant supervision of Cédric Galliot form CSS, EMPA, during the modelling and calculations,

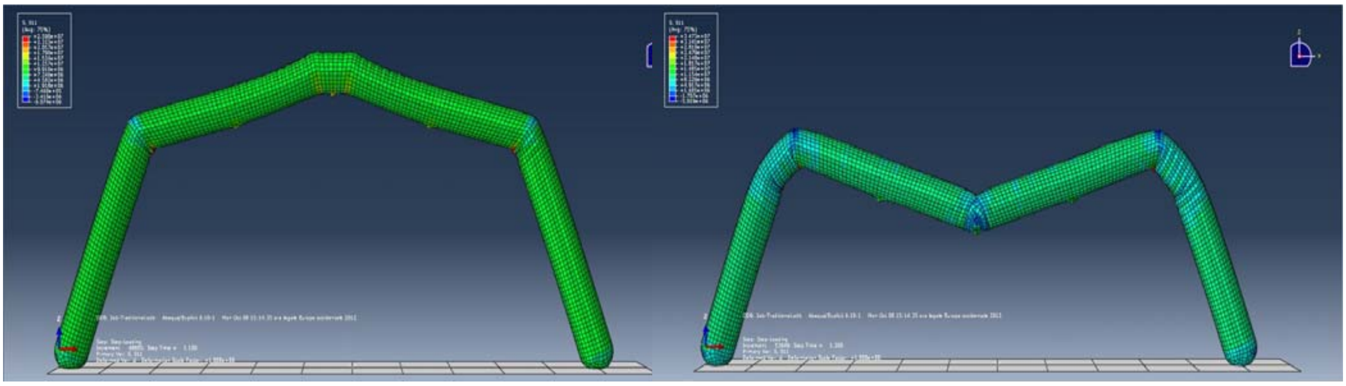


FIG. 4.67-68: COLLAPSE OF THE STANDARD ARCH UNDER DISTRIBUTED LOADING

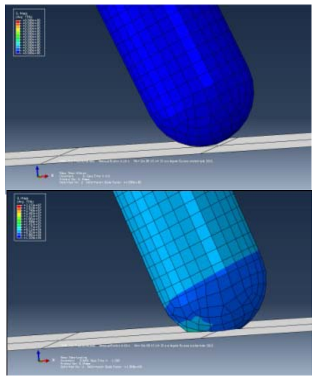


FIG. 4.69-70: MODEL OF THE INFLATABLE PART

When struts were present, the load was applied to these elements while, in the case of inflatable structures only, loads were applied directly to the membrane.

In the case of Tensairity® the boundary condition at the ends of the arch was applied easily by constraining two nodes in all three directions, while, in the case of an only inflatable structure, a horizontal plane which cannot move or deform acts as ground level.

4.4.3. Results

From the physical tests a feeling of the behaviour of arches was deduced. Some of these results are shown in the graphs below.

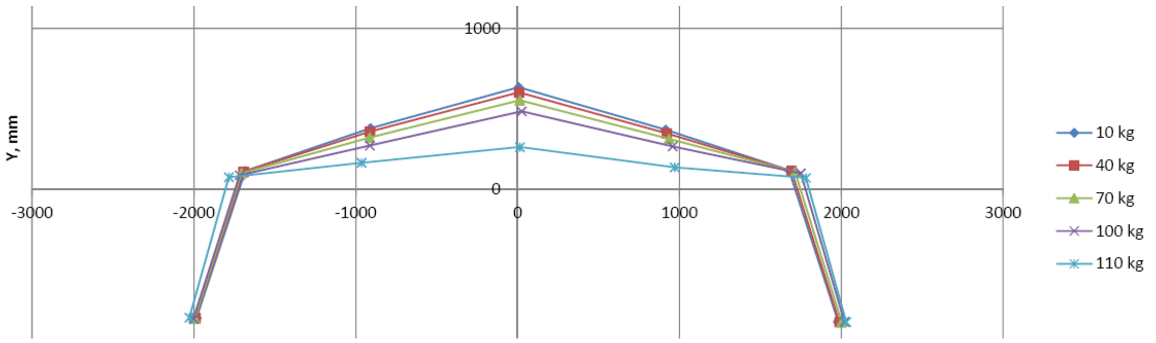


FIG. 4.71: DEFORMATION SEGMENTED ARCH 300 MILLIBAR

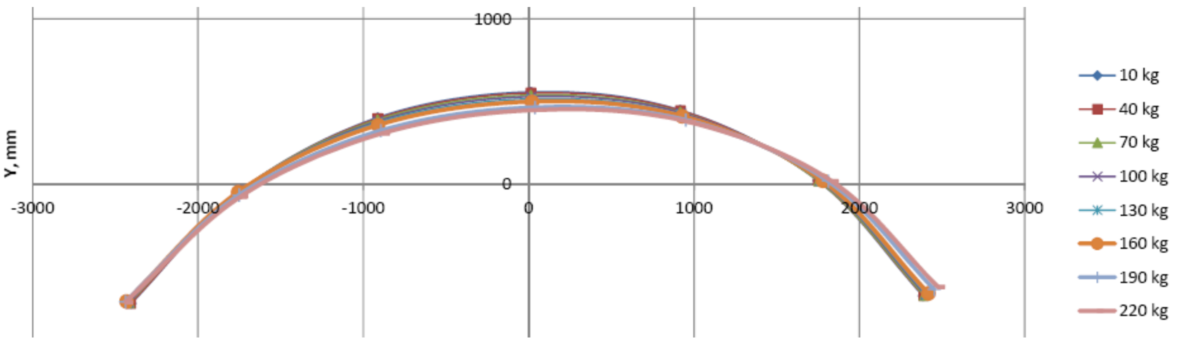


FIG. 4.72: DEFORMATION TENSAIRITY® SMOOTH ARCH 300 MILLIBAR

Some other tests were carried out without the support of the digital image correlation system and therefore only the ultimate load bearing capacity is reported. From the overall experience of these tests, the following results can be listed (see the table below).

VERY LIMITED LOAD BEARING CAPACITY

FIG. 4.74: TEST OF PROTOTYPE 4 WITH A LOAD BEARING CAPACITY 2 TIMES HIGHER

Prototype	Description	Ultimate load	
		200 millibar	300 millibar
3	Segmented "O" section	≅ 70kg	≅ 100kg
4	Segmented, Tensairity® "O" section	≅150kg	≅ 230kg
5a	Smooth, "Web" section	≅ 100kg	≅ 130kg
5b	Smooth, Tensairity® "Web" section	≅ 160kg	≅ 260kg

From these data, the ultimate load-bearing capacity of the Tensairity® arch (number 5b) appears to be more than two times higher compared to the segmented one, even if its span is 20% longer. The pressure level gives an additional increment of load-bearing capacity which is fairly linear.

At any rate, due to the manufacturing, loading system and foundations, the collapse of the structure appeared much earlier than the expected value that came from numerical analysis. This was particularly true for the Tensairity® arch with web (number 5). In fact, probably due to a manufacturing defect (which is not so visible when the arch is not loaded), the arch is not symmetrical and therefore the right hand side bent much more than the other side. As a consequence, buckling of the system appeared sooner and always at the same position, in contrast with the behaviour of the segmented arch which collapsed vertically as foreseen in the numerical analysis too.

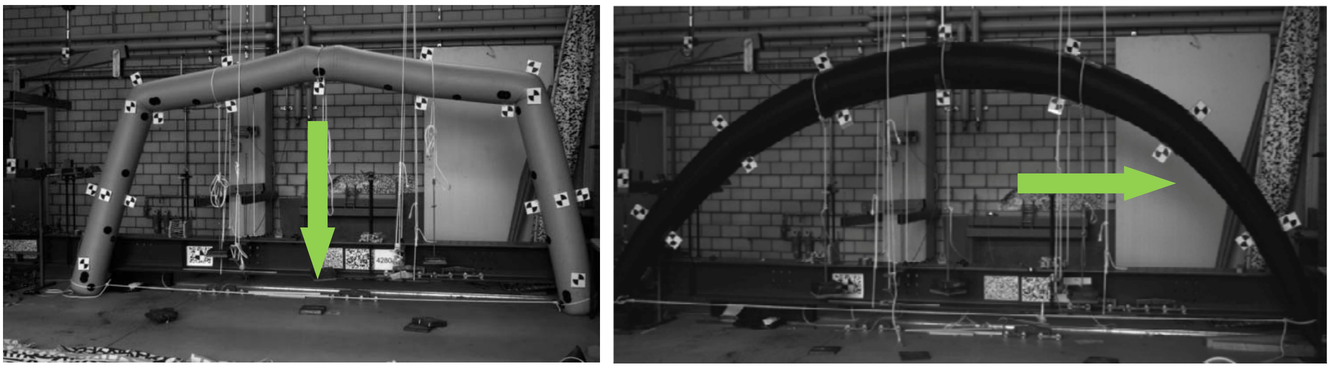


FIG. 4.75-76: COLLAPSING BEHAVIOUR OF SEGMENTED AND SMOOTH ARCHES

In any event, a more detailed report on the behaviour of different inflatable arches will be presented in a further publication after an extension of the testing campaign and, if possible, construction of extra mock-ups to better validate results.

4.5. Durability of parts

As highlighted in Chapter One, every innovation needs to be supported by careful studies of the risks it brings. In the case of inflatable structures, the main concern among practitioners regards the fragility of a load-bearing structure made out of a textile fabric which can be punctured or damaged, especially during the mounting phases. In addition, past experience with inflatable systems that were not airtight sullied the name of the pneumatic solution. For this reason, tests on the air-tightness of the structure were carried out alongside the architectural and technological investigations.


FIG. 4.77: AIR TIGHTNESS TESTS ON A ZIP

4.5.1. Air-tightness

Air-tightness depends on three main variables:

1) the nature of the material used
2) the arrangements of seam lines to prevent the flow of air through fibres
3) the air-tightness of the seam lines and valves which depends on the welding process, the precision of the welding machine, and the accuracy of the operators.

Air passes thorough every material and thin layer material like PES/PVC or other fabrics are no exception. Thicker material ensures better performance as regards air-tightness thanks to the coating which is, in general, more homogeneous compared to very thin layers of coating.

But the majority of air escapes in another way: as presented already in paragraph 4.1.2, air may flow through fibres and therefore leave the hull easily. To avoid this problem there are two options: some fabric includes a process of fibre impermeabilization to prevent (or reduce to a minimum) the penetration of air through the weft and warp threads. The other option is a careful cutting pattern and assembly method as shown in picture 4.76. Sometimes correct seam arrangements mean longer manufacturing time and, therefore, greater cost.

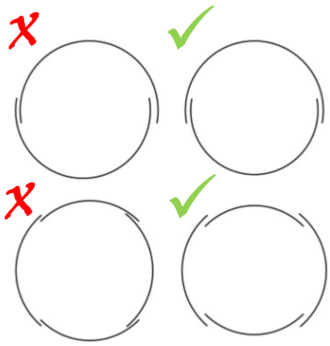


FIG. 4.76: WELDING ARRANGEMENTS TO ASSURE AIR-TIGHTNESS

Errors in manufacturing generate the third category of air losses. Luckily, these problems can be easily detected before the delivery of the structure and therefore the system can be repaired or substituted.

Anyway, for all these reasons, double layer systems solve the majority of the problems and, even if the material is double, the total production cost could well be the same or even cheaper with additional major advantages in terms of maintenance, repair and weight.

4.5.2. Welding tests

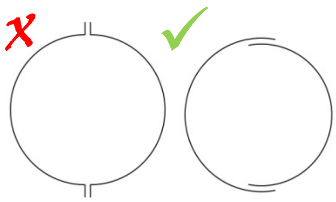


FIG. 4.77: WELDING ARRANGEMENTS TO PREVENT PEELING

There is also another problem related to the arrangement of seam lines: i.e., a wrong arrangement of panels can lead to peeling problems as happened for the first two experiments with the smooth arch prototype. So, as shown in picture 4.77, even if the arrangement on the left might be correct to prevent air loss through the fibres, it does not work from a structural point of view due to peeling. In fact, if the fibres are coupled in a reversed way, as soon as stresses are introduced, they tear apart and all the forces enter the

FIG. 4.78: MONO-AXIAL TEST, EMPA LABORATORIES

coating which has very limited tensile strength. On the contrary, in planar welding the fibres collaborate perfectly. To understand better what the tensile strength of reversed seam lines might be, a mono-axial test on welding was carried out.

Four different welds on several different materials (PVC or PU coated) were checked: configurations one and two are characterised by 4mm welding lines while configurations three and four show samples of 40mm welding.

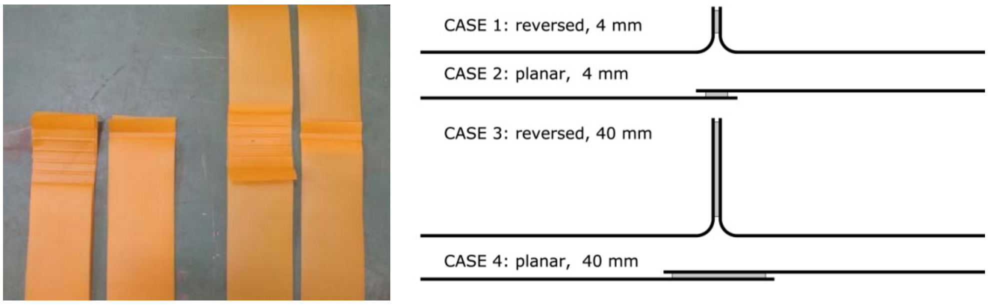


FIG. 4.81-82: SAMPLES AND WELD ARRANGEMENTS

The results confirm that cases 1 and 3 are the weakest samples and their tensile strength is pretty limited or even null while both cases 2 and 4 do not influence the tensile strength of the whole sample because the stripes do not break at the weld (where the amount of material is double) but above or below, where there is only a single layer of textile.

4.5.3. Biaxial tests

Biaxial tests were carried out to identify the material properties and, in particular, the deformation of the fabric when loaded in two directions. In point of fact, an inflatable structure is a perfect example of a double curved fabric stressed differently in warp and weft directions. As shown by the basic formulas presented in paragraph 3.1.1, hoop stress is a function of the pressure and the radius and is twice the axial stress at the same point.

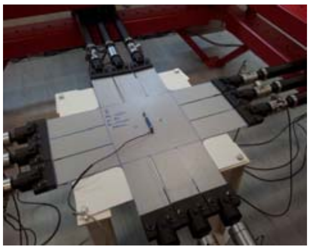


FIG. 4.81: BIAXIAL TEST, POLITECNICO DI MILANO

Therefore, to better understand how the structure would deform under inflation, a series of biaxial tests could prove extremely helpful if one would like to come up with accurate results. In the text rig one would be able to simulate the stresses that act in the structure when it is being tested, assembled, and in operation. In fact, as soon as an inflatable is manufactured, all producers test the air-tightness by keeping the arch inflated for a certain period of time (usually one day) at a higher pressure (in the case of similar structures, up to 500 millibar). Then, if no leaks are present, the arch is deflated and it is included among the shelters that are designed for an operational pressure of 300 millibar.

Following this procedure a load profile was identified by calculating the tensile stress on the surface from the pressure and the radius of curvature. This procedure proved extremely accurate in the case of segmented arches where the seam lines do not perturb the homogenous surface. In the case of the smooth arch, on the contrary, the influence of the seam lines, as explained in paragraph 4.4 prevails, with unpredictable deformations.

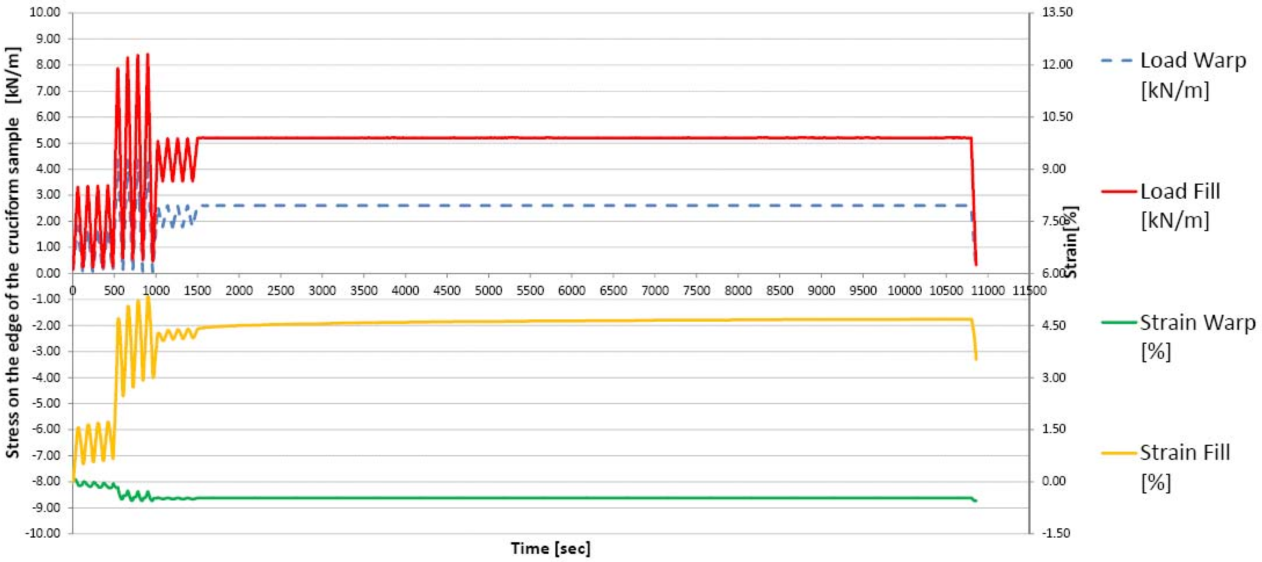


FIG. 4.84 EXAMPLE OF BIAXIAL TEST OF PES/PVC, 1100 G/M²

4.6. Materials and details

The success of *ARK* depends on its simplicity in use, the performance of the materials and the functionality of the details. The main topics discussed in the following paragraphs relate to textile material for the inflatable part, the struts for the reinforcements, the ropes for stabilization, the foundation, and connectors with other ARKs. All these factors influence both the performance (from the load-bearing capacity to the durability of the system) and the weight of the final solution. From this author's point of view, weight and transportation volume are the main drivers for ARK to successfully establish itself in the humanitarian sector, therefore they are the first criteria whose materials and details will be specified.

Learning from the discussions with practitioners, the target weight of one ARK is set at 15kg to facilitate its transportation either by women or children. This must include reinforcement, packaging and hand pumps while its bulk should be able to be stockpiled on standard pallets.

To make a comparison, manufactured prototypes weights are shown in the table below.

Prototype	Material	Total surface	Total weight
4	PES/PVC 1100g/m^2 coated both sides	9.5m^2	10.5kg
5	PES/PVC 900g/m^2 coated both sides	11.8m^2	10.6kg

Prototype 5 has a vertical web which is more or less 2m^2 and this is the main reason for the difference which is balanced by the use of a lighter material.

4.6.1. The inflatable part

Weight can be drastically reduced with the application a double layer system which is even more airtight than thick coated polyester coated fabrics, thereby solving the problem of pressure loss. Moreover, due to the small radial dimensions (0.125m), the hoop stress introduced in the membrane is not critical therefore any material with a tensile strength above 900N/5cm could be suitable for this application[5]. Consistent perforation strength[6] values are welcome, to protect the PU-bladder.

Material should be either wieldable or easy to sew and its connections should not affect the durability of the system. After extensive experience with weldable materials, the second option is more advisable.

Given these minimal requirements, a reasonable target weight for the membrane part of one double layer ARK can be set at 5kg which can be composed as follows:

Material	Weight	Total surface
PES/PVC	300g/m^2	10m^2
PU bladder	200g/m^2	10m^2
Total weight		5kg

CAMPING TENTS

These calculations do not include the valves or 1-2m^2 of reinforcements which might be applied mainly in the foundation areas, where the arch might get punctured or scratched.

4.6.2. The struts and reinforcements

FIG. 4.86: PLATE CONNECTION BASED ON BOLTS AND NUTS

A large variety of materials can be used as reinforcements such as FRP, bamboo[7] or metal elements. Anything that can be found on site is welcome for all the reasons presented in Part I. These components, if they are distributed in the kit, must be demountable into pieces no longer than 1 metre. The connection details of the struts must be sturdy and able to resist both compression and tension, therefore connections like the one shown in picture 4.85 do not work. In the prototypes extra plates were used to connect the elements using nuts and bolts (picture 4.86). For the testing the system worked efficiently but assembly time was definitely too long. A better and faster solution needs to be identified also on site.

The target weight for the reinforcement elements, in the case of distribution within the ARK kit is 6kg.

Examples of materials and dimensions can be found in the table below.

5 Tarpaulin approved by IFRC presents a tensile strength of 500N/5cm (UNI EN ISO 1421:2000)

6 UNI EN ISO 5421 1983

7 Humanitarian Bamboo (2009) *A manual on the humanitarian use of bamboo in Indonesia*.

Material	Profile	Geometry	Total weight
Aluminium	Tube	Ø 12mm	4.9
	Plate	15mm*6mm	4.1
	Double Keder profile	-	6.3
Steel	Plate	10mm*5mm	6.5
	Pipe	10mmØ t=3mm	6.5
Wood	Plate	25mm*15mm	4.6
PVC	Double Keder profile	-	4.0
Total weight for 16.5 metres			Btw 4-6.5kg

4.6.3. The foundations

The problem of the foundations was solved by integrating them with the packaging and transportation system. A cylindrical bucket made out of plastic was selected as the most promising solution both for the transportation (it can be rolled from the warehouse to the exact location of deployment) and the reuse phases due to the extreme necessity, in the case of an emergency to collect goods or to contain, for example, water. Once deployed, the bucket can be buried in the ground or even filled with debris to improve its stability. Plastic material might be the most effective for this kind of application.

T he target weight of this component is set at 1kg.

FIG. 4.87: EXAMPLE OF BUCKETS FOR FOUNDATION

4.6.4. Other components

ARK must be connected to cladding material in the simplest and fastest way, for this reason flaps with eyelets or ribbons should be included.

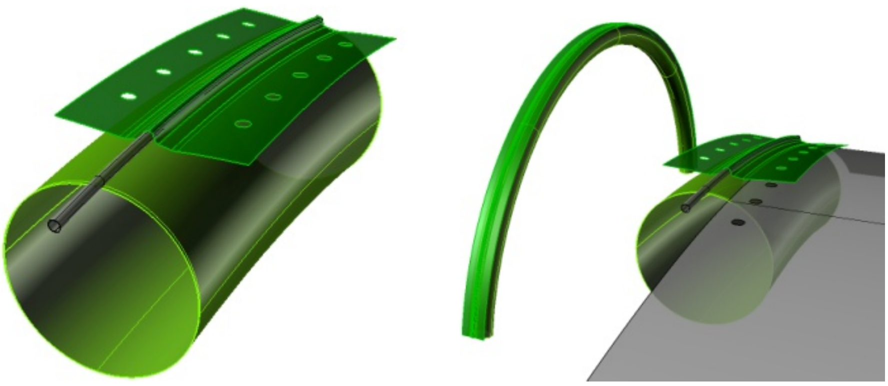


FIG. 4.88-89: FLAPS AND POCKET COMBINED

Hand pump for guy ropes and 4 pickets might be useful too.

All these extra components have a target weight of 4kg which gives a total weight of 15kg as discussed above.

5 CONCLUSIONS

The research presented in Part II into an implementable structural system for emergency applications proved that there is room for innovation in emergency but that the success of the solutions goes far beyond the architectural or technological fields.

From this author's point of view, the future of humanitarian assistance needs to go in the direction of *open processes* where all actors, from NGOs to victims, passing via researchers and industries, participate towards achieving the same goals: i.e. development and independence for the affected community.

OPEN PROCESSES

The consolidation of this approach passes through an extensive application of the *transitional settlement* principles which have not yet been fully applied in the humanitarian sector. Sheltering, considered as a combination of process and products, must go in the direction of the distribution of simple open and implementable tools (components) which address very basic needs while development is assured through bottom-up strategies in subsequent phases.

DISTRIBUTION OF BASIC TOOLS

All this process is synthesised in a *progressive approach* that is able to link the very first hours after an emergency strikes and the development phase though the distribution of components whose use is not prescribed from the top, but can be identified on site, even at the moment of installation, through simple and fast adaptation to the contingency of each problem.

FROM THE VERY FIRST HOURS TO THE DEVELOPMENT PHASE

In the case of ARK, examples of application in standard scenarios have been foreseen, as presented in Chapter 2 of this part and in the next paragraphs too.

At any rate, this Author wants to stress the idea that these sketches show only a limited range of the possible solutions that can be identified thanks to the collaboration of all the actors involved in the humanitarian process. For all these reasons, the ARK structural component should not to be locked into a specific layout or form otherwise it may lose its innovative nature and specific advantages.

In this way, this research wants to stress the ultimate goal of sheltering, namely, assistance for and improvement in the life quality of an affected community. From this point of view, the products and processes of sheltering become mere tools which facilitate the achievement of this goal.

5.1. The structural component

At the component level, ARKs fill the gap of rapid deployable structural elements which are usually critical and difficult to provide in the very first hours. The advantage of ARK is its simplicity in use. For this reason, lightness and speed of assembly prevail over load-bearing properties which could be improved at a later stage of the implementation of construction.

MINIMIZATION OF RISKS OF FAILURE

Moreover, inflatable technology offers its best in terms of minimization of risks of failure. In fact, the inflatable component of ARK, once pumped up, cannot break but, at worst, can bend or deform greatly, for example, under strong wind or unexpected loadings. As was proved by the loading test, as soon as these forces end, the structure pops back up to its standard configuration without plastic deformation.

In this way, one might say the only risk of failure that might occur is a puncture of the air chamber, however this chance is limited thanks to the application of a double layer system where high tenacity fabric protects the inner bladder.

5.2. The "A" shelter

The most simple and effective arrangement of ARKs for prompt recovery is based on two arches and plastic sheeting covering the volume they create.

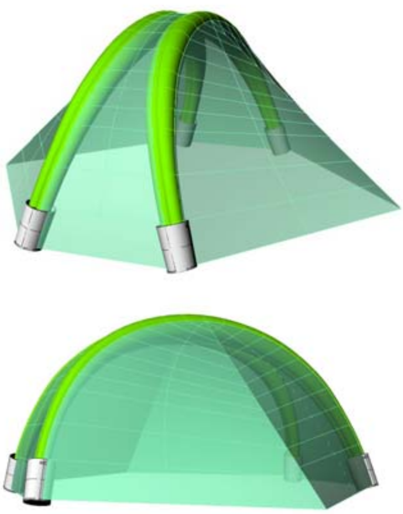


FIG. 5.1-2: "A" SHELTER PROSPECTIVE VIEWS

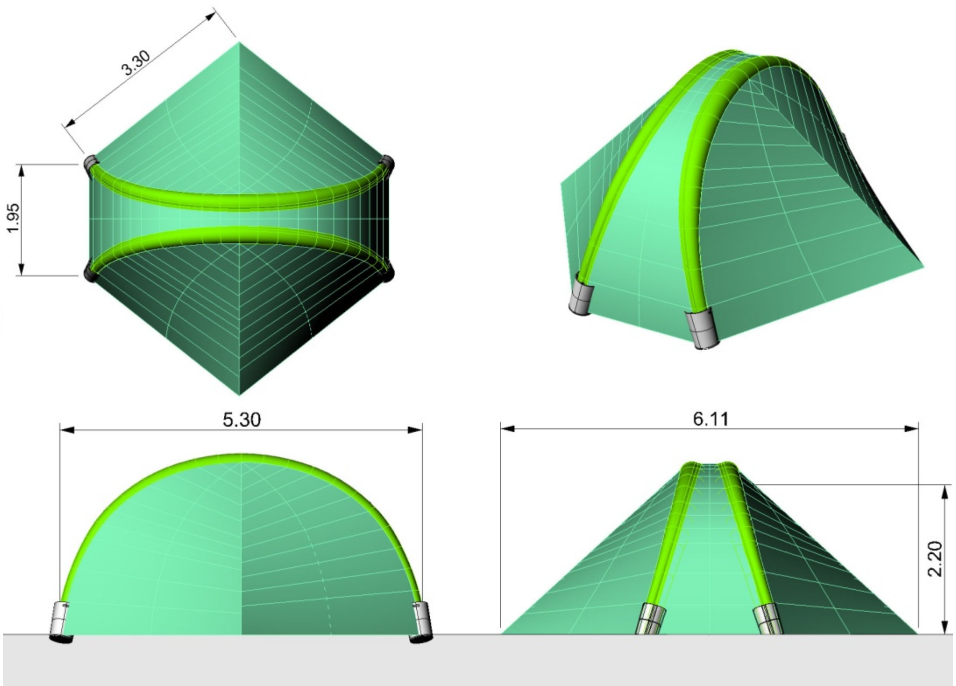


FIG. 5.3: GENERAL DIMENSIONS OF "A" SHELTER

This configuration is designed to shelter people from the very first hours and has been identified for different reasons which range from simplicity in assembly to the limited amount of material involved.

Moreover, covering $20m^2$, the “A” shelter has the interesting peculiarity that the enclosed space can be provided using a flat (or almost flat) membrane as shown in picture 5.5 and, therefore, cladding can be arranged even on site, using any fabric available locally or can easily be produced out of tarpaulin foils, following the scheme presented in picture 5.6.

Due to the self equilibrated geometry guy ropes are limited or even not necessary, especially in the very first hours. At any rate, from the moment they become essential, they can be applied vertically in the inner part as shown in 5.4, occupying only the space the shelter covers with a huge advantage in terms of the use of the space near the shelter.

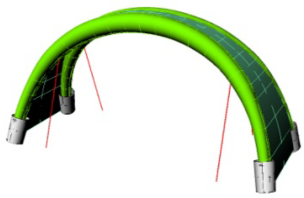


FIG. 5.4: POSITION OF GUY ROPES

The target weight for a rapidly deployable “A” shelter, (included the cladding i.e. tarpaulin and reinforcement struts) is around 45kg (15kg each ARK plus 9.6kg for two tarpaulins which weigh approximately 200g per m^2). The transportation weight can be reduced by 10-15% where the struts can be provided on site.

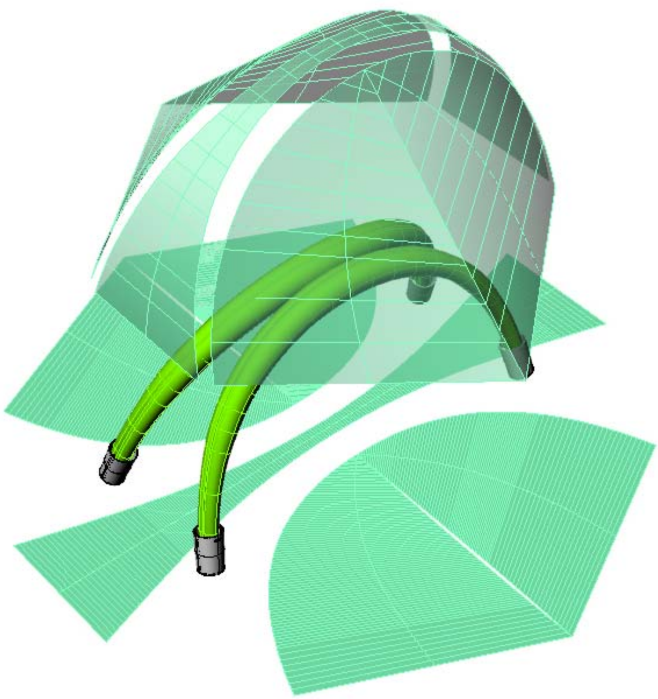


FIG. 5.5: THE COMPONENTS OF AN “A” SHELTER

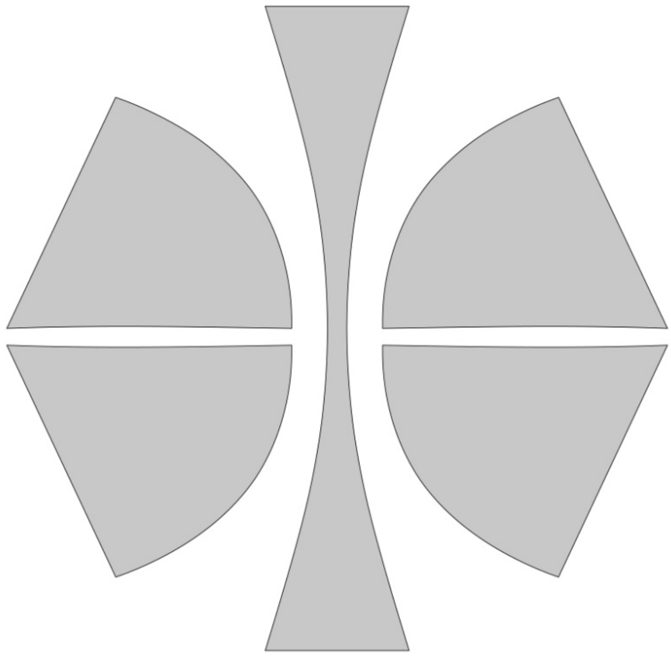


FIG. 5.6: CUTTING PATTERN FOR THE CLADDING

Double layer cladding can be installed according to the climate and availability of resources: the top layer can simply be laid on top of the roof while the second can be attached from the inner side to the lower struts of the ARKs

5.3. Further steps of the research

The potential of rapidly deployable structural systems is promising but the process that brings to their of application in the humanitarian sector might be long. To ensure a smooth and effective application of this principle in an emergency this author foresees two strategies which might run in parallel.

On the one hand, the effectiveness of the optimization of simple ARK configurations such as the above-mentioned “A” shelter must be carefully checked through field tests starting from an application in a pilot project under the supervision of practitioners. Larger aggregations of ARKs as collective or community shelters assembled by NGOs when needed, might prove a perfect test too. Experience about aggregation of arch-shaped structural elements must be shared among practitioners and victims too at it has been done with plastic sheeting strategy.

On the other hand, the principle based on the aggregation of arches might be pushed into other fields such as sports and leisure where the end users are willing to assemble and participate in the implementation of these kinds of devices to build a covering. The optimisation process, thanks to these inputs, would certainly be faster and more complete.

The support of NGOs and sector industries is essential for the success of both strategies.

After three years of research and experiments on emergency and inflatable technology this Author still believes that the fastest path to innovate the sector would come from the application of technologies already tested in other fields. It is a fact that Tensairity® didn’t break through in architecture yet, even if the diffusion of an high efficient arch-based construction system might radically innovate the sector of temporary architecture and Tensairity®, thanks to its characteristics of lightness, speed of set up and the sheer beauty of the system might play a key role. The sectors of leisure, exhibition, sports and temporary activities in general are constantly looking for new and effective solutions which simplify and speed up the construction process and therefore, are the best fields of experiment one could find. Unfortunately, inflatable structures suffer unsuccessful past experiences or untimely applications which slow down the establishment of a promising technology whose benefit needs to be transferred to the humanitarian field as soon as possible.

A1 APPENDIX 1: DEFINITIONS

The following definitions were not written by this author (unless specified) but are a collection of official definitions shared by people operating in humanitarian sectors. Terms under debate are presented here with different definitions. The majority of these definitions have been established by MünichRe/Geo Risks Research Department and CRED. More information on definitions can be found on the EM-DAT website in the "Glossary" section[1].

Adaptive capacity: Long-term strategies for change within a society mostly for future hazards and climate change.

Catastrophe: according to Quarantelli[2] this differs from a disaster for four different reasons. First of all, in a catastrophe, the community-built infrastructure is heavily impacted; secondly, local officials are unable to carry out their organizational role and work; thirdly, most of the everyday community functions are interrupted; fourthly, help from nearby communities cannot be provided due to the fact that neighbours are also heavily affected.

Collective Centre[3]: For the purposes of these guidelines, this term describes a transitional settlement option, consistent with the following definition. Collective Centres also referred to as mass shelters, are usually transit facilities located in pre-existing structures, such as community centres, town halls, gymnasiums, hotels, warehouses, disused factories or

---

[1] www.emdat.be/glossary

[2] Quarantelli E. L. (2000) Emergency, disasters and catastrophes are different phenomena, University of Delaware, disaster research center.

[3] Corsellis, T. and Vitale, A. (2005) *Transitional settlement: displaced populations*. Oxfam, Oxford

unfinished buildings. They are often used when displacement occurs inside a city, or when there are significant flows of displaced people into a city or town.

Coping capacity: Refers to "resources for a direct response to the impact of a given hazard event, this would include disaster preparedness and early warning.

Disaster[4]: A situation or event that overwhelms local capacity, necessitating a request at a national or international level for external assistance (definition considered in EM-DAT); An unforeseen and often sudden event that causes great damage, destruction and human suffering. Though often caused by nature, *disasters* can have human origins. Wars and civil disturbances that destroy homelands and displace people are included among the causes of disasters. Other causes can be: building collapse, blizzard, drought, epidemic, earthquake, explosion, fire, flood, hazardous material or transportation incident (such as a chemical spill), hurricane, nuclear incident, tornado, or volcano (*Disaster* Relief)

Disaster: Any natural or man-made event causing much suffering, distress or loss e.g. earthquake, drought, flood, fire, hurricane, tornado, tidal wave, explosion, epidemic (UN-Habitat 1992)

Drought[5]: Long-lasting event triggered by a lack of precipitation. A drought is an extended period of time characterized by a deficiency in a region's water supply that is the result of constantly below average precipitation. A drought can lead to losses in agriculture, affect inland navigation and hydropower plants, and cause a lack of drinking water and famine.

Early recovery[6]: A process which seeks to catalyse sustainable development opportunities by generating self- sustaining processes for post-crisis recovery. It encompasses livelihoods, shelter, governance, environment, and social dimensions, including the reintegration of displaced populations, and addresses underlying risks that contributed to the crisis.

Earthquake[7]: Shaking and displacement of ground due to seismic waves. This is the earthquake itself without secondary effects. An earthquake is the result of a sudden release of stored energy in the Earth's crust that creates seismic waves. They can be of tectonic or volcanic origin. At the Earth's surface they are felt as a shaking or displacement of the ground. The energy released in the hypocentre can be measured in different frequency ranges. Therefore there are different scales for measuring the magnitude of a quake according to a certain frequency range. These are: a) surface wave magnitude (Ms); b) body wave magnitude (Mb); c) local magnitude (ML); d) moment magnitude (Mw).

---

[4] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

[5] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

[6] Shelter centre (2010 a) *Shelter after disaster: strategies for transitional settlement and reconstruction*, Geneva

[7] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

Emergency[8]: Sudden and usually unforeseen event that calls for immediate measures to minimise its adverse consequences.

Exposure: Countries or other “entities’ affected by natural hazards such as floods, earthquakes, droughts, storms, floods and sea level rise.

Extreme winter condition[9]: Damage caused by snow and ice. Winter damage refers to damage to buildings, infrastructure, traffic (especially navigation) inflicted by snow and ice in the form of snow pressure, freezing rain, frozen waterways, etc.

General flood[10]: Gradually rising inland floods (rivers, lakes, groundwater) due to high total depth of rainfall or snowmelt. A general flood is caused when a body of water (river, lake) overflows its normal confines due to rising water levels. The term general flood additionally comprises the accumulation of water on the surface due to long-lasting rainfall (water logging) and the rise of the groundwater table above surface. Furthermore, inundation by melting snow and ice, backwater effects, and special causes such as the outburst of a glacial lake or the breaching of a dam are subsumed under the term general flood. General floods can be expected at certain locations (e.g. along rivers) with a significantly higher probability than at others

Hazard[11]: Threatening event, or probability of occurrence of a potentially damaging phenomenon within a given time period and area.

Hazard[12]: source of potential harm

Hazard[13]: A potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro meteorological and biological) or induced by human processes (environmental degradation and technological hazards). Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterised by its location, intensity, frequency and probability.

Homeless: Number of people needing immediate assistance for shelter

---

[8] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

[9] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

[10] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

[11] CRED (2012), *Annual disaster statistic review 2011*, Ciaco Imprimerie, Louvain-la-Neuve

[12] ISO 73:2009

[13] UNISDR (2008), *Disaster Risk Reduction Strategies and Risk Management Practices: Critical Elements for Adaptation to Climate Change*

Innovations[14]: Innovations are dynamic processes which focus on the creation and implementation of new or improved products and services, processes, positions and paradigms. Successful innovations are those that result in improvements in efficiency, effectiveness, quality or social outcomes/impacts.

Mitigation[15]**:** Activities providing a critical foundation in the effort to reduce the loss of life and property from natural and/or manmade disasters by avoiding or lessening the impact of a disaster and providing value to the public by creating safer communities. Mitigation seeks to fix the cycle of disaster damage, reconstruction, and repeated damage. These activities or actions, in most cases, will have a long-term sustained effect.

MSF: *Medecins sans Frontieres*. An international humanitarian medical organisation

Non-food item[16]: For the purposes of these guidelines, this term describes the basic goods and supplies required to enable families to meet personal hygiene needs, prepare and eat food, provide thermal comfort and build, maintain or repair Shelters

Preparedness[17]**:** Activities and measures taken in advance to reduce or avoid possible damages from potential or impeding threats and to be ready to assist those who have been adversely affected by a disaster and need help beyond their coping mechanisms. This includes the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations.

Preparedness[18]**:** Actions that involve a combination of planning, resources, training, exercising, and organizing to build, sustain, and improve operational capabilities. Preparedness is the process of identifying the personnel, training, and equipment needed for a wide range of potential incidents, and developing jurisdiction-specific plans for delivering capabilities when needed for an incident.

Prevention[19]**:** Actions to avoid an incident or to intervene to stop an incident from occurring. Prevention involves actions to protect lives and property. It involves applying intelligence and other information to a range of activities that may include such countermeasures as deterrence operations; heightened inspections; improved surveillance

---

[14] ANLAP (2009), *8th review on humanitarian sector, performance impacts and innovations*

[15] DHS, Federal Emergency Management Agency (FEMA), (2008), National Response Framework Glossary/Acronyms

[16] Sphere project, The (2004), *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response*, Geneva

[17] UNISDR (2008), *Disaster Risk Reduction Strategies and Risk Management Practices: Critical Elements for Adaptation to Climate Change*

[18] DHS, Federal Emergency Management Agency (FEMA), (2008), National Response Framework Glossary/Acronyms

[19] DHS, Federal Emergency Management Agency (FEMA), (2008), National Response Framework Glossary/Acronyms

and security operations; investigations to determine the full nature and source of the threat; public health and agricultural surveillance and testing processes; immunizations, isolation, or quarantine; and, as appropriate, specific law enforcement operations aimed at deterring, pre-empting, interdicting, or disrupting illegal activity and apprehending potential perpetrators and bringing them to justice.

Recovery[20]**:** The development, coordination, and execution of service- and site-restoration plans; the reconstitution of government operations and services; individual, private-sector, nongovernmental, and public-assistance programs to provide housing and to promote restoration; long-term care and treatment of affected persons; additional measures for social, political, environmental, and economic restoration; evaluation of the incident to identify lessons learned; post incident reporting; and development of initiatives to mitigate the effects of future incidents

Relief[21]**:** The provision of assistance or intervention during or immediately after a disaster to meet the life preserving and basic subsistence needs of those people affected. It can be of immediate, short-term or protracted duration

Recovery[22] Decisions and actions taken after a disaster so that survivors are able to re-build their lives and livelihoods in a manner that reduces further exposure to disaster risks. This necessarily includes the organisation of post-disaster interventions from a risk reduction perspective

Resilience: The ability of a system, community or society potentially exposed to hazards to resist, absorb, adapt to and recover from the stresses of a hazard event, including the preservation and restoration of its essential basic structures and functions.

Residual risk: The risk that remains in unmanaged form, even when effective disaster risk reduction measures are in place and for which emergency response and recovery capacities must be maintained.

Response: The provision of emergency services and public assistance during or immediately after a disaster to save lives, reduce health impacts ensure public safety and meet the basic subsistence needs of the affected people.

---

[20] DHS, Federal Emergency Management Agency (FEMA), (2008) National Response Framework Glossary/Acronyms

[21] UNISDR (2008), *Disaster Risk Reduction Strategies and Risk Management Practices: Critical Elements for Adaptation to Climate Change*

[22] UNISDR (2008), *Disaster Risk Reduction Strategies and Risk Management Practices: Critical Elements for Adaptation to Climate Change*

Response[23]**:** Immediate actions to save lives, protect property and the environment, and meet basic human needs. Response also includes the execution of emergency plans and actions to support short-term recovery.

Rescue

Risk[24]**:** "the expected number of lives lost, persons injured, damage to property and disruption of economic activity due to a particular natural phenomenon, and consequently the product of specific risk and elements at risk. […] "the capacity of a system, community or society to resist or to change in order that it may obtain an acceptable level in functioning and structure. This is determined by the degree to which the social system is capable of organising itself, and the ability to increase its capacity for learning and adaptation, including the capacity to recover from a disaster."

Risk[25]**:** effect of uncertainty on objectives

Shelter[26]**:** A habitable covered living space, providing a secure, healthy living environment with privacy and dignity for the groups, families and individuals residing within it

Shelter[27]**:** Shelter is a critical determinant of survival in the Initial stage of an emergency. Beyond survival, shelter is necessary to provide security and personal safety, protection from the climate and enhanced resistance to ill health and disease. It is also important for human dignity and to sustain family and community life as far as possible in difficult circumstances. Shelter and associated settlement and non-food item responses should support communal coping strategies, incorporating as much self-sufficiency and self-management into the process as possible

Susceptibility: Susceptibility refers to selected structural characteristics of a society and the framework conditions in which communities face potential natural hazards and climate phenomena.

Tarpaulin[28] A strong flexible waterproof sheet of fabric or plastic.

Tarpaulin: HDPE laminated both sides with LDPE[29]

[23] DHS, Federal Emergency Management Agency (FEMA), (2008) National Response Framework Glossary/Acronyms

[24] Cardona, O.D., (2003), *The need of rethinking the concept of vulnerability and risk from an holistic prospective: a necessary review and criticism for effective risk management*, Earthscan Publishers, London.

[25] ISO 73:2009

[26] Corsellis T. and Vitale A. (2005) Transitional Settlement for Displaced Population, University of Cambridge Shelter Project, Oxfam, Oxford

[27] Sphere project, The (2004), *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response*, Geneva

[28] www.plastic-sheeting.org/

[29] IFRC (2009 a) *Emergency Items Catalogue*

Tent[30]: Portable shelter with a cover and a structure

Transitional shelter: In these guidelines, this term describes a family shelter which provides a habitable covered living space and a secure, healthy living environment, with privacy and dignity, for both displaced or non-displaced occupants over a period between a conflict or natural disaster and the completion of transitional reconstruction, that is intended to be relocated, upgraded, or disassembled for materials, and that may be supported as an assistance method.

Transitional shelter[31]: A shelter which provides a habitable covered living space and a secure, healthy living environment, with privacy and dignity, for those within it, during the period between a conflict or natural disaster and the achievement of a durable shelter solution

Transitional Shelter : A transitional shelter provides a habitable covered living space and a secure, healthy living environment, with privacy and dignity to occupants during the period between a natural disaster and the achievement of a durable shelter solution[32].

Tsunami[33]: ("wave in the port" in Japanese): Waves advancing inland. A tsunami is a series of waves caused by a rapid displacement of a body of water (ocean, lake). The waves are characterised by a very long wavelength and their amplitude is much smaller offshore. The impact in coastal areas can be very destructive as the waves advance inland and can extend over thousands of kilometres. Triggers of a tsunami can be: earthquakes, volcanic eruptions, mass movements, meteorite impacts or underwater explosions.

UV Ultraviolet. Solar radiation with wavelengths 200-400nm wavelength. UV is the component of sunlight that is most damaging to plastic sheeting.

Victims: sum of dead and total people affected by a disaster

Vulnerability: Combination of countries' social conditions, including susceptibility, coping capacities and adaptive capacities.

---

[30] UNOCHA, (2004), Tents: a guide to the use and logistics of family tents in humanitarian relief, UN publications

[31] Corsellis T. and Vitale A. (2005) Transitional Settlement for Displaced Population, University of Cambridge Shelter Project, Oxfam, Oxford

[32] Corsellis, T. and Vitale A. (2005) Transitional Settlement for Displaced Population, University of Cambridge Shelter Project, Oxfam, Oxford

[33] CRED (2012), Annual disaster statistic review 2011, the numbers and trends, Ciaco Imprimerie, Louvain-la-Neuve

A2 GENERAL BIBLIOGRAPHY

1. Alexander D.E., (1993) *Natural Disasters, Disaster and hazard mapping*, Springer..
2. ALNAP, Slim, H. (2006), *Global welfare: A realistic expectation for the international humanitarian system?* in ALNAP Review of Humanitarian Action: Evaluation Utilisation, Overseas Development Institute, London. Available at: www.alnap.org/publications/RHA2005/ rha05_Ch1.pdf.
3. ALNAP , Cosgrave, J., (2008 a), *Responding to earthquakes: learning from earthquake relief and recovery operations*. London. Available at: www.alnap.org/pool/files/ALNAPLessonsEarthquakes.pdf
4. ALNAP, Clark P. Ramalingam B., (2008 b), *Organizational change in the humanitarian sector in7th Review of humanitarian action.*
5. ALNAP O'Donnell et al., (2009 a), *Responding to urban disasters: learning from previous response and recovery operations*. London. Available at: www.alnap.org/pool/files/alnap-provention-lessons-urban.pdf.
6. ALNAP, Ramalingam B. and Mitchell J. with Borton J. and Smart K. (2009 b) *8th review on the humanitarian sector, Chapter 1: Counting what counts: performance and effectiveness in the humanitarian sector.*
7. ALNAP, Proudlock K. and Ramalingam B. with Sandison P., (2009 c) *8th review on the humanitarian sector, Chapter 2: Improving humanitarian impact assessment: bridging theory and practice.*
8. ALNAP, Ramalingam B., Scriven K. and Foley C. (2009 d) *8th review on humanitarian sector, Chapter 3: Innovations in International humanitarian action.*
9. ALNAP, (2010 a), *Haiti Earthquake Response*, Context analysis.
10. ALNAP Rencoret N. et al., (2010 b), *Haiti earthquake response; context analysis*. London. Available at: www.alnap.org/pool/files/haiti-context-analysis-final.pdf.
11. ALNAP Buchanan-Smith M. with Scriven K., (2011), *Leadership in action: leading Effectively in Humanitarian Operations.*
12. ALNAP, Taylor G., Stoddard A., Harmer A., Haver K., Harvey P., (2012), *State of the humanitarian system.*
13. Anderson M. B., (1999), *Do no harm: how aid can support peace - or war,* Lynne Rienner Publishers, London.
14. Ashdown, P., (2011), *Humanitarian Emergency Response Review,* DFID London. Available at: www.dfid.gov.uk/Documents/publications1/HERR.pdf.
15. Austen P. D., *Targeting the vulnerable in emergency situations: who is vulnerable?,* In The Lancet vol. 348, 1996.
16. Baird M. E., (2010), *Phases of emergency management*, Prepared for the Intermodal Freight Transportation Institute (IFTI), University of Memphis.
17. Berger H., (1996), *Light Structures - Structures of Light: The Art and Engineering of Tensile Architecture*, Birkhauser Verlag, Base.
18. Berkum, S., (2007), *The Myths of Innovation,* O'Reilly Press, Sebastopol.
19. Bertoldini M., Campioli A., (2009), *Progettare oltre l'emergenza: spazi e tecniche per l'abitare temporaneo,* Il Sole 24 ore, Milano.
20. Bletzinger K.-U., (1998), *Formfinding and Optimization of Membranes and Minimal Surfaces Formfinding with the Updated Reference Strategy (URS),* Lecture notes, prepared for the PhD-course: Advanced school on Advanced Topics In Structural Optimization.

21. Boano, C., (2011), *Violent spaces: production and reproduction of security and vulnerabilities,* The Journal of Architecture, 16: 1, pp37-55. Available at: dx.doi.org/10.1080/13602365.2011.547002
22. Boano, C. and Hunter, W., (2011), *Architecture at risk (?): The ambivalent nature of post-disaster practice,* Oxford Brookes University, Oxford.
23. Brookes A. J., Poole D., (eds), (2004), *Innovation in architecture*, Spon Press, London, New York.
24. Brown O., Crawford A., Hammill A., (2006), *Natural Disasters and Resource Rights: Building resilience, rebuilding lives,* IISD, International institute for sustainable development. Available at: http://www.iisd.org/adaptation.
25. Capasso A., (1991), *Strutture tessili per l'architettura, advisory board on the built environment, commission on engineering and technical systems*, National research council, CUEN, Napoli.
26. Capasso A., (1993), *Le tensostrutture a membrana per l'architettura: introduzione alla progettazione*, Maggioli, Rimini.
27. Cardona, O.D., (2003), *The need of rethinking the concept of vulnerability and risk from an holistic prospective: a necessary review and criticism for effective risk management.* In *Mapping Vulnerability: Disasters, Development and People,* G. Bankoff, G. Frerks, D. Hilhorst (Ed), Earthscan Publishers, London.
28. Carra G., Beccarelli P. Maffei R., (2012), *Interaction between fibre-glass profiles and membranes for building active tensile structures*, IASS-APCS 2012, Seoul.
29. CDA, (2004), *Do No Harm Handbook*.
Available at hwww.cdainc.com/dnh/docs/DoNoHarmHandbook.pdf.
30. Chalinder, A. (1998) *Temporary human settlement planning for displaced populations in emergencies*, ODI, London.
31. Christoplos, I. (2006) *Links between relief, rehabilitation and development in the tsunami response*. London: Tsunami Evaluation Coalition. Available at: ochanet.unocha.org/p/Documents/TEC_LRRD_Report.pdf
32. Clermont, C., Sanderson, D., Sharma, A. and Spraos, H. (2011) *Urban disasters - lessons from Haiti: Study of member agencies responses to the earthquake in Port au Prince, Haiti, January 2010*. Disasters Emergency Committee, London.
33. COHRE, (2006), *The Pinheiro principles: United Nations principles on housing and property restitution for refugees and displaced persons*, COHRE, Geneva.
34. Corsellis T. and Vitale A., (2005) *SAME: Shelter Assessment Monitoring and Evaluation*.
35. Corsellis, T. and Vitale, A. (2005) *Transitional settlement: displaced populations*. Oxfam, Oxford.
36. Crawford, K., Suvatne, M., Kennedy, J., Corsellis, T. (2010) *Urban shelter and the limits of humanitarian action,* In *Forced Migration Review* Issue 34, February 2010, pp27-28. Available at: www.fmreview.org.
37. CRED, Guha-Sapir D., Vos F., Below R., Ponserre S., (2012), *Annual disaster statistical review 2011: the numbers and trends*, Ciaco Imprimerie, Louvain-la-Neuve.
38. CRED, Guha-Sapir D., Vos F., Below R., Ponserre S., (2011), *Annual disaster statistical review 2010: the numbers and trends*, Ciaco Imprimerie, Louvain-la-Neuve.
39. Crettol R., Gauthier L. P., Luchsinger R. H. Vogler R, (2010), *Tensairity Arches, Proceedings of the International Association for Shell and Spatial Structures (IASS)* Symposium 2010, Shanghai.
40. Crichton, D. (1999), *The Risk Triangle*, in Ingleton, J. (ed.), Natural Disaster Management, Tudor Rose, London.
41. Dayton-Johnson, J., *Natural Disasters and Adaptive Capacity,* OECD Working Paper 237, 2004, p.18
42. David A. (2002). *Principles of Emergency Planning and Management*. Oxford: Oxford University Press.
43. Davis J., Lambert R. (eds.) (2002), *RedR, Engineering in Emergencies: A Practical Guide for Relief Workers, 2nd ed.*, RedR/ITDG, London.
44. Davis, M. (2007) *Planet of slums*. London, Verso.
45. Debacker W, Henrotay C, De Wilde W. P., Hendrickx H, (2006), *Adaptable versus lightweight designs of transitory dwellings,* Proc. of 1st Conf. on Ravage of the Planet, Management of Natural Resources, Sustainable Development and Ecological Hazards, eds. C.A. Brebbia, M.E. Conti, E.Tiezzi, 331-339 Wessex Institute of Technology, UK.
46. De Pauw C., Lauritzen E., (Eds.), (1994), *Disaster planning, structural assessment, demolition & recycling: report of task force 2 / of RILEM technical committee 121, DRG,* London.
47. De Laet L., Luchsinger R. H., Crettol R., Mollaert M., De Temmerman N., (2009), *Deployable Tensairity Structures*, Journal of the International Association for Shell and Spatial Structures, Pellegrino (eds.), vol. 50, n. 2, pp. 121-128.
48. DHS, Federal Emergency Management Agency (FEMA), (2008), *National Response Framework Glossary/Acronyms*. Available at: www.fema.gov/pdf/emergency/nrf/nrf-glossary.pdf.
49. ELRHA, (2011), *Guide to constructing effective partnerships*. Available at: www.elrha.org.
50. ELRHA, Walker P., Russ C., (2010), *Professionalising the humanitarian sector*, ELRHA.
51. Erkelens P.A., Van Egmond E., (2009), *Towards innovative (emergency) sheltering*, SASBE 2009.

52. Fischer M., Bletzinger K.-U., Wüchner R., (2010) *FE-Simulation and Optimal Design of Smart Adaptive Lightweight Structures*, Proceeding of the ECCM2010, IV European Conference on Computational Mechanics Palais des Congrès, Paris.
53. Fuller R. B., (1975) *Synergetics: Explorations in the Geometry of Thinking,* MacMillan Publishing Co., Inc., NewYork.
54. Garcia B., Bain W., Paul H. (Eds), (2000), *Earthquake architecture: new construction techniques for earthquake disaster prevention,* Loft publications, New York
55. Geipel R., (1982), *Disaster and reconstruction: the Friuli (Italy) earthquakes of 1976,* Allen & Unwin, London.
56. Gijsbers, R., Cox, M.G.D.M., Haas, T.C.A. de, Kok, P. & Hulsbergen, H. (2009). ***Development of a membrane roofing system with integrated climate control for community shelters.*** In A. van den Dobbelsteen, M. van Dorst & A. van Timmeren (Eds.), *Smart Building in a changing climate*, pp. 133-147, Techne Press, Amsterdam
57. Giurdanella V., Zanelli A., (2006), *Lightweight, adaptable and reversible construction: sustainable strategies for housing,* Adaptables 2006. International Conference on Adaptable Building Structures, Eindhoven, The Netherlands.
58. Giurdanella V, Zanelli A., (2010) *Temporary building intended as adaptable and reversible building: a sustainable strategy for housing – The recent situation in Italy*. In: New Perspective in Industrialization in Construction - A State-of-the-art Report, G. Girmscheid, F. Scheublin.
59. Goudarzi S. (2006), *Flocking to the Coast: World's Population Migrating into Danger*, Live Science: Environment. 18 July, 2006. Available at: www.livescience.com/4167-flocking-coast-world-population-migrating-danger.html
60. Government of Haiti (2010) *Post Disaster Needs Assessment. Port au Prince: Assessment of damage, losses, general and sectoral needs*. Port au Prince, Government of the Republic of Haiti.
61. Gründig L., Ekert L., Moncrieff E., (1996) *Geodesic and Semi-Geodesic Line Algorithms for Cutting Pattern Generation of Architectural Textile Structures*, in Lan, T.T., (Ed.), proceeding of Asia-Pacific conference on shell and spatial Structures IASS, Beijing, China.
62. Gründig L., Moncrieff E., Singer P. and Ströbel D., (2000), *High performance cutting pattern generation of architectural textile structures*, IASS-ICAM, Fourth International Colloquium on Computation of Shell & Spatial Structures, Crete, Greece.
63. Hamdi, N. (2010 a) *The placemaker's guide to building community*, Earthscan, London.
64. Hamdi, N. (2010 b) Foreword. In: Lyons, M., Schilderman, T., Boano, C. (eds.) (2010) *Building Back Better. Delivering people-centred housing reconstruction at scale*. London, Practical Action Publishing, pp: ix-xi.
65. Haq B., Chattopadhayay-Dutt P. (2007), *Battling the storm, study on cyclone resistant housing*, German Red Cross, Bangladesh.
66. Harvey, D. (2006) *Spaces of Global Capitalism: towards a theory of uneven geographical development*. London, Verso.
67. Henrotay C., DebackerW. , Mollaert M., De Wilde W.P. and Hendrickx H,. (2006), *Four dimensional design: a strategy for efficient shelter and sustainable housing after conflict-based and natural disasters* Proc. of 1st Conf. on Ravage of the Planet, Management of Natural Resources, Sustainable Development and Ecological Hazards, eds. C.A. Brebbia, M.E. Conti, E.Tiezzi, 341-350 Wessex Institute of Technology, UK.
68. Herzog T., (1977), *Pneumatic structures: a handbook for the Architect and Engineer*, Crosby Lockwood, London.
69. Holling, C.S., Walker B. (2003) *Resilience Defined,* Internet Encyclopaedia of Ecological Economics.
70. Humanitarian Bamboo (2009) *A manual on the humanitarian use of bamboo in Indonesia*. Available at: www.humanitarianbamboo.org.
71. IASC (2006 a), *Gender Handbook: Women, girls, boys and men, different needs, equal opportunities*, United Nations.
72. IASC (2006 b) *Guidance note on using the cluster approach to strengthen humanitarian response:* available at www.unhcr.org/refworld/docid/460a8ccc2.html
73. IASC (2011) *Haiti Shelter Cluster website*. Available at https://sites.google.com/site/shelterhaiti2010/
74. IASC (2010 a) *Final strategy for meeting humanitarian challenges in urban areas*. Geneva, United Nations.
75. IASC (2010 b) *Haiti: Transitional Shelter Needs Analysis*.
76. IASC (2010 c) *Response to the humanitarian crisis in Haiti*. Geneva, United Nations. Available at: www.humanitarianinfo.org/iasc/pageloader.aspx?page=content-news-newsdetails&newsid=143
77. IFRC (2007 a), *Fixing plastic sheeting to wood and the ground,* Geneva
78. IFRC, Oxfam, (2007 b), *Plastic sheeting, a guide to the specification and use of plastic sheeting in humanitarian relief*, Geneva
79. IFRC, (2009 a) *Emergency Items Catalogue,* Available at procurement.ifrc.org/catalogue/
80. IFRC, (2009 b) Ferrer C. Serra I., (eds) Ashmore J. Treherne C., *The IFRC shelter kit,* Geneva

81. IFRC (2010 a) *Haiti Recovery Assessment: Volume 1 - Synthesis Report*. Geneva.
82. IFRC (2010 b) *Owner-driven housing reconstruction guidelines*. Geneva
83. IFRC (2010 c) *World Development Report 2010 focus on urban risk*. Geneva, IFRC. Available at: www.ifrc.org/Global/Publications/disasters/WDR/WDR2010-full.pdf
84. IFRC (2011 a) *Transitional shelter - Eight designs*, Geneva
85. IFRC (2011 b) *Shelter department annual report 2010*, Geneva
86. IFRC (2012) *Road to resilience: bridging relief and development for a more sustainable future*, IFRC discussion paper on resilience - June 2012, Geneva, 2012
87. Ingleton, J. (ed.), *Natural Disaster Management*, Tudor Rose, London
88. IHRC, (2011), *Haiti One Year Later: The Progress to Date and the Path Forward*. Port au Prince, Government of Haiti.
89. International Covenant on Economic, Social and Cultural Rights, available at: www2.ohchr.org/english/law/cescr.htm
90. International Crisis Group, (2010), *Haiti: Stabilisation and reconstruction after the quake*. Brussels, International Crisis Group. Latin America/Caribbean report no.32
91. Kaltenborn, B. P., Nellemann, C., Vistnes, I. I. (Eds), (2010), *High mountain glaciers and climate change,* UNEP, United Nations Environment Programme, GRID-Arendal
92. Kapucu N., Garayev V., (2011), *Collaborative decision-making in emergency and disaster management,* International Journal of Public Administration, 34: 366-375, Taylor & Francis Group, LLC
93. Kennedy J., Ashmore, J., Babister, E., Kelman I., (2008), *The Meaning of "Build Back Better": Evidence From Post-Tsunami Aceh and Sri Lanka*, in *Journal of Contingencies and Crisis Management*, Vol.16(1), pp:24-36.
94. Kronenburg R., (2000), *Portable Architecture*, Architectural Press, Oxford.
95. Kronenburg R., (2005), *Houses in motion, the genesis, history and development of portable building*, academy Editions, London.
96. Kronenburg R., (2007), *Flexible : architecture that responds to change,* Laurence King Publishing, London.
97. Lennon A., (2008), *Geometrical Mechanics for Inflatable Structures*, Fourth European Workshopon Inflatable Space Structures ESTEC, Noordwijk, Netherlands.
98. Lewis, J. (2008), *"The Exigent City",* The New York Times (June 8th, 2008). Available at: www.nytimes.com/2008/06/08/magazine/08wwln-urbanism-t.html
99. Lewis W. J., (2003)*, Tension structures: form and behaviour*, Thomas Telford, London
100. Lewis, W. J., Lewis, T. S., (1996), *Application of Formian and dynamic relaxation to the form finding of minimal surfaces*, Journal of the IASS, Vol 37, pp 165-186
101. Lichtenberg, J.J.N.(2005), *Slimbouwen®, a strategy for product development*, Proceedings of the ARCOM conference 2005, London
102. Lo Iacono A., Troiano M., (2002), *Psicologia dell'emergenza*, Editori Riuniti, Roma
103. Lou C. M., (2004), *Development and application of space inflatable structures*, 22nd International Symposium on Space Technology and Science, Morioka, Japan.
104. Lyons, M., Schilderman, T., Boano, C. (eds.) (2010) *Building Back Better. Delivering people-centred housing reconstruction at scale*, Practical Action Publishing, London.
105. Lyons, M., (2009) *Building Back Better: The Large-Scale Impact of Small-Scale Approaches to Reconstruction*. *World Development*, Vol. 37(2), pp: 385-398.
106. Luchsinger R.H., Pedretti, A., Steingruber, P. & Pedretti, M. (2004): *The new structural concept Tensairity: Basic Principles*, in Progress in Structural Engineering, Mechanics and Computation, ed A. Zingoni, A.A. Balkema Publishers, London.
107. Maffei R. (2009), Innovative lightweight construction: water and membrane, Master thesis, Politecnico di Milano
108. Maffei R., Carra G., Beccarelli P., Galliot C., Zanelli A., (2012) *Design of inflatable complex shapes and geometrical analysis of pneumatic structures*, IASS-APCS 2012, Seoul.
109. Maffei R., Luchsinger R. Zanelli A. (2011) *Design tools for inflatable structures*, International Conference on Textile Composites and Inflatable Structures STRUCTURAL MEMBRANES 2011, Barcelona
110. Maidique, A.M. (1984), *Entrepreneurs, Champions and Technological Innovation*, Sloan Management Review, Harvard
111. Maiowiecki M. (1985), *Tensostruttura: progetto e verifica*, CISIA, Milano
112. Malighetti L. E. (2000) *Progettare la flessibilità*, Edizioni clup, Milano.
113. Martignoni M, Melizi L., Minoia R. (2012) *TenT-Re*. *Progetto di un sistema costruttivo evolutivo tessile per le diverse fasi dell'emergenza*, Master thesis, Politecnico di Milano
114. Masotti C., (2010), *Manuale di architettura di emergenza e temporanea: soluzioni per l'edilizia temporanea nomade ed estrema,* Sistemi Editoriali, Napoli.

115. Maslow A.H., (1943), *A theory of human motivation,* Psychological Review 50(4): 370-96. Available on line at: psychclassics.yorku.ca/Maslow/motivation.htm.
116. McGraw-Hill Science & Technology Dictionary.
117. Mirtschin J., (2011), *Generative Models Utilized for Superior Design Development*, International Symposia IABSE-IASS 2011: Taller, Longer, Lighter, London.
118. Moiraghi M., (2007) *Civil protection: from emergency management to homeland security: origin, development and methods,* Maggioli, Milano.
119. Mori T.,(2002), *Immaterial Ultramaterial: Architecture, Design and Materials*, Harvard Design School, Cambridge
120. Mulgan G., Tucker S., Ali R. & Sanders B., (2007), *Social Innovation*, Oxford: Skoll centre for social entrepreneurship.
121. Neal, D. (1997), *Reconsidering the Phases of Disaster*, International Journal of Mass Emergencies and Disasters, Vol. 15, No. 2, August, 239-264.
122. NRHA- *Natural Hazards Risk Atlas 2011*, Maplecroft.
123. OECD, (2009), *Sustainable manufacturing and Eco-innovation, framework, practices and measurements.*
124. Osman A. and Sebake N. (2010) "*Time" as a key factor in design and technical decision-making: concepts of accessibility, affordability, participation, choice, variety and change in the South African Housing sector* in *Human Settlements Review*, Volume 1, Number 1.
125. Otto F. (2004), *On the Way to an Architecture of the Minimal*, in "Brian Forster", Marijke Mollaert (eds), *European Design Guide for Tensile Surface Structures*, TensiNet, Brussel.
126. Oxfam (2010) *Haiti: A Once-in-a-Century Chance for Change*. Oxford, Oxfam. Available at: www.oxfam.org/sites/www.oxfam.org/files/bp136-haiti-once-in-a-century-220310.pdf.
127. Oxfam (2011) *Haiti: Progress report 2010*. Oxford, Oxfam. Available at: www.oxfam.org/sites/www.oxfam.org/files/haiti-progress-report-2010-en.pdf.
128. *OED* (Oxford English Dictionary), (2011), Oxford University Press, Oxford. Available at: www.oed.com.
129. Oxford Essential Dictionary of the U.S. Military The, (2001) Oxford University Press Staff, Berkley Books.
130. Paoletti I., Pellavio M., (2005), *Innovare l'emergenza: tecnologie spalleggiabili per abitare in ambienti critici,* Milano.
131. Pawley M. (1990) *Theory and design in the second machine age*, Basil Blackwell Ltd, Oxford
132. Peduzzi P., Dao H., Herold C., (2005), *Mapping Disastrous Natural Hazards Using Global Datasets*, in Natural Hazards, Springer.
133. Pielke R., *Hurricanes and Human Choice*, WSJ.
134. Portoghesi P., (1999), *Natura e architettura*, Skira, Milano.
135. Pravettoni R. in Kaltenborn, B. P., Nellemann, C., Vistnes, I. I. (Eds), (2010), *High mountain glaciers and climate change*, UNEP, GRID-Arendal.
136. Pugh A., (1976) *An introduction to tensegrity*, University of California Press, Berkely.
137. Punurai W., Tongpool W., Morales J. H., (2012) *Implementation of genetic algorithm for optimum cutting pattern generation of wrinkle free finishing membrane structures*, in Finite Elements in Analysis and Design, Vol. 58 pp. 84-90.
138. Quarantelli, E. L., (2000), *Emergency, disasters and catastrophes are different phenomena*, University of Delaware, disaster research center.
139. Quarantelli, E. L., (1999), T*he disaster recovery process: What we know and do not know from research*. Disaster Research Center, University of Delaware. Available at: dspace.udel.edu:8080/dspace/bitstream/handle/19716/309/PP%20286.pdf?sequence=1.
140. Quzai, U., (2010), Pakistan: Implementing people-centred reconstruction in urban and rural areas. In: Lyons, M., Schilderman, T., Boano, C. (eds.) (2010) *Building Back Better. Delivering people-centred housing reconstruction at scale*. London, Practical Action Publishing, pp: 113-134.
141. Rapoport A., (1969), *House form and culture*, Prentice-hall, Englewood cliffs, US.
142. RCRC, (2011), *Climate guide 2011*, available at: www.climatecentre.org.
143. Reitman, J., (2011), *How the World Failed Haiti*, Rolling Stone, 4 August. Available at: www.rollingstone.com/politics/news/how-the-world-failed-haiti-20110804.
144. Richardson P., Dietrich L, Ed. (2001), *XS: big ideas, small buildings*, Thames & Hudson, London.
145. Rieff, D., (2002), *A bed for the night: humanitarianism in crisis*, New York: Vintage.
146. Roekens J., Mollaert M. De Laet L. Luchsinger R. H. (2011) *Preliminary investigation to Tensairity arches,* International Conference on Textile Composites and Inflatable Structures Structural Membranes 2011, Barcelona.
147. Sanderson, D., Kennedy, J., Sharma, A., Burnell, J. (2011) *Lost in transition. Principles, practice and lessons from Haiti for urban post-disaster shelter recovery programmes*. Draft of forthcoming paper.
148. Sarger R., (1967), *Structures Nouvelles,* Bruxelles, Centre d'etudes architecturales.

149. Schilderman, T. (2010) Putting people at the centre of reconstruction. In: Lyons, M., Schilderman, T., Boano, C. (eds.) (2010) *Building Back Better. Delivering people-centred housing reconstruction at scale*, Practical Action Publishing, pp: 7-38, London.
150. Shelter Centre (2009) *Transitional shelter prototypes*, Geneva.
151. Shelter Centre (2008) *Transitional settlement and reconstruction after natural disaster*, Shelter Centre, Geneva.
152. Shelter Centre (2010 a) *Shelter after disaster: Strategies for transitional settlement and reconstruction*, Shelter Centre, Geneva.
153. Shelter Centre (2010 b) *Transitional shelter standards*, Geneva.
154. Shelter Centre (2010 c) *Urban shelter guidelines: Assistance in urban areas to populations affected by humanitarian crises*, Shelter Centre, Geneva.
155. Shelter Centre (2011) *Transitional shelter guidelines*, Geneva.
156. Siegal J., ed. (2002) *Mobile: the art of portable architecture,* Princeton Architectural Press, New York
157. Siegal J. ed. (2008), *More mobile : portable architecture for today,* Princeton architectural press, New York.
158. Sinopoli N., Tatano V., (eds), (2002) *Sulle tracce dell'innovazione : tra tecniche e architettura,* Serie di architettura, FrancoAngeli, Milano.
159. de Soto, H., (2000), *The mystery of capital: why capitalism triumphs in the West and fails everywhere else*. New York, Basic Books.
160. Slaughter E.S., (1998), *Models of Construction Innovation,* Journal of Construction Engineering and Management, 124 (2) 226-231.
161. Spence R., Manfield P., Corsellis T., (2000) *Cold climate emergency shelter system, a research project for humanitarian organizations*, Cambridge University.
162. Sphere project, The (2004), *The Sphere Handbook: Humanitarian Charter and Minimum Standards in Humanitarian Response*, Geneva, The Sphere Project Available at: www.sphereproject.org/component/option,com_docman/task,cat_view/gid,70/Itemid,203/lang,english/.
163. Stimpfle B. (2008), "Structural Air – Pneumatic Structures", in Textile Composites and Inflatable Structures II (Computational Methods in Applied Sciences), edited by Eugenio Oñate, Bernd Kröplin.
164. Ströbel D., Singer P., (2007), *New Developments for cutting pattern of membranes*, Proceeding of the conference Structural Membranes 2007, Barcelona.
165. Terpolilli C., Bologna R. (eds), (2005), *Emergenza del progetto, progetto dell'emergenza: architetture con-temporaneità,* F. Motta, Milano.
166. The Ant Farm (1973), *Inflatocookbook*, self published.
167. Tidd J., Bessant J., Pavitt K., (1997), *Managing innovation : integrating technological, market and organisational change*, John Wiley, Chicester.
168. Till, J. (2007) *Architecture and Contingency,* In *Field Journal*. Vol 1 (1), pp:120-135.
169. Topham S. (2002), *Blowup, Inflatable art, architecture and design*, Prestel.
170. Turoff, M., White, C., Plotnick, L., Hiltz, S. R. (2008). *Dynamic emergency response management for large scale decision making in extreme events*. Proceedings of the 5th International Information Systems for Crisis Response and Management (ISCRAM) Conference (pp. 462-470). Washington, DC: ISCRAM.
171. Turri E., (2003) *Gli uomini delle tende. Dalla mongolia alla Mauritania*, Bruno Mondadori, Milano
172. UN (1998) *Urban Land Policies for the Uninitiated*. New York: United Nations. Available at: www.unescap.org/huset/land_policies/index.htm.
173. UN (2010) *World Population Prospects, the 2010 Revision*. New York: United Nations. Available at: esa.un.org/unpd/wpp/Excel-Data/population.htm.
174. UNDP (2010) *Human Development Report 2010: The Real Wealth of Nations: Pathways to Human Development*. New York, United Nations. Available at: hdr.undp.org/en/media/HDR_2010_EN_Complete_reprint.pdf.
175. UNDP CPR (United Nations Development Programme Crisis Prevention and Recovery) (2007) *Guidance Note on Early Recovery*. New York, United Nations.
176. UNDRO (now UNOCHA) (1982) Davis I., *Shelter after disaster: Guidelines for Assistance*, UN, New York. Available at: sheltercentre.org/sites/default/files/UNDRO_ShelterAfterDisaster.pdf
177. UN Habitat (2003) *The Challenge of Slums* New York, United Nations. Available at: www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=1156.
178. UN Habitat (2009 a) *Global Report on Human Settlements 2009: Planning Sustainable Cities*. New York, United Nations. Available at: www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2831
179. UN Habitat, (2009 b) *Shelter projects 2008*, Geneva
180. UN Habitat, (2010 a) *Shelter projects 2009*, Geneva
181. UN Habitat (2010 b) *State of the World's Cities 2010/2011 - Cities for All: Bridging the Urban Divide*. New York, United Nations. Available at: www.unhabitat.org/pmss/listItemDetails.aspx?publicationID=2917
182. UN Habitat, (2011), *Shelter projects 2010*, Geneva

183. UNHCHR, (1991) *The Right to Adequate Housing* (Article 11 (1) Covenant on Economic, Social and Cultural Rights), CESCR General Comment 4, 12 December 1991. New York, United Nations. Available at: www.unhchr.ch/tbs/doc.nsf/0/469f4d91a9378221c12563ed0053547e?Opendocument
184. UNHCR, (2007), *Handbook for Emergencies, Third Edition*. Geneva, United Nations. Available at: www.unhcr.org/publ/PUBL/471db4c92.html.
185. UNHCR*, IOM, (2010), Collective centres guidelines 2010.* Available at http://preparativosyrespuesta.cridlac.org/XML/eng/doc18990/doc18990-contenido.pdf.
186. UNISDR, (2005), *Hyogo Framework for Action (HFA) 2005-2015: Building the resilience of nations and communities to disasters*, Extract from the final report of the World Conference on Disaster Reduction.
187. UNISDR, (2008), *Disaster Risk Reduction Strategies and Risk Management Practices: Critical Elements for Adaptation to Climate Change,* Inter agency. Available at www.unhcr.org/refworld/docid/4a2d189d10.html
188. UNISDR, (2009), *Terminology on disaster risk reduction*. Available at: unisdr.org/files/7817_UNISDRTerminologyEnglish.pdf
189. UNISDR, (2012), *Making cities resilience report 2012.* Available at: www.unisdr.org/campaign
190. UNOCHA, (2004), *Tents: a guide to the use and logistics of family tents in humanitarian relief,* UN publications
191. UNOCHA, (2005), *Humanitarian response review.* United Nations. New York. Available at: ochaonline.un.org/OchaLinkClick.aspx?link=ocha&docid=34198
192. UNOCHA, (2006), *Exploring key changes and developments in post disaster settlement, shelter and housing, 1982 – 2006. Scoping study to inform the revision of "Shelter after Disaster: Guidelines for Assistance"* UN publication.
193. UNOCHA, (2007), *The Four Pillars of Humanitarian Reform, New York.* Available at www.icva.ch/ngosandhumanitarianreform.html
194. UNOCHA (2011), *One response website.*
Available at: oneresponse.info/AboutUs/Pages/About%20Us.aspx
195. UNPD, (2009), *World Urbanization Prospects: The 2011 Revision*. New York: United Nations. Available at: esa.un.org/unpd/wup/index.htm
196. *Universal Declaration of Human Rights*, available at: www.un.org/en/documents/udhr/index.shtml
197. UNU-EHS, (2011), *World risk report 2011*. Available at: ihrrblog.org/2011/09/26/2011-un-world-risk-index/
198. Zanelli A., (2003), *Trasportabile trasformabile : idee e tecniche per architetture in movimento*, CLUP, Milano
199. Walker B., J. A. Meyers. (2004) *"Thresholds in ecological and social-ecological systems: a developing database"* Ecology and Society 9(2)
200. White, S. (2008) *Turning ideas into action: innovation within the humanitarian sector. A think piece for the HFP Stakeholders Forum*, Humanitarian Futures Programme, London. Available at: www.humanitarianfutures.org/sites/default/files/InnovationsThinkPiece.pdf
201. Whitman, M. E., Mattord M. E. (2007) *Principles of incident response and disaster recovery,* Thomson, Boston
202. Witkin A., (1997), *Physically Based Modelling: Principles and Practice*, *Particle System Dynamics,* Robotics Institute, Carnegie Mellon University.
203. World Bank, (2010), *Natural Hazards, Unnatural Disasters: the economics of effective prevention*. Washington DC, World Bank and United Nations Available at: www.gfdrr.org/gfdrr/nhud-home
204. World Bank, GFDRR, Global Facility for Disaster Reduction and Recovery, Jha A. K., Duyne Barenstein, J., Phelps, P. M.; Pittet, D.; Sena, S. (2010), *Safer Homes, Stronger Communities, A Handbook for Reconstructing after Natural Disasters,* The World Bank, Washington DC. Available at: www.housingreconstruction.org/housing/

Selection of relevant websites:

1. www.innovativeshelter.tue.nl/: website of the conference “Innovative shelter” organized by Technische Universiteit Eindhoven in 2007.
2. www.preventionweb.net with useful information for the field of prevention
3. hdr.undp.org which collect all Human development reports
4. http://reliefweb.int/country/cod database to inform humanitarians worldwide offered by OCHA
5. www.undp.org, United Nation development programme
6. www.plastic-sheeting.org, detailed information about the use and installation of tarpaulin
7. www.sheltercluster.org a resource for humanitarian agencies working in the Shelter and Non-Food Items (NFIs) sector. It contains real-time documents and materials for use during the emergency and recovery phase of humanitarian responses across the world.
8. www.humanitarianresponse.info is provided by UN OCHA to support humanitarian operations globally
9. www.icva.ch/ngosandhumanitarianreform.html, with useful information about the humanitarian reform
10. www.speedkits.eu, the European founded project about rapid deployable kits
11. procurement.ifrc.org/catalogue/, IFRC non food items catalogue
12. www.emdat.be
13. www.unhcr.org/refworld database of all humanitarian publications