Origami-Nano-Technological Refugee Tent

Omar M Amireh PhD, Associate Professor

Department of Architecture, University of Jordan
amireh@ju.edu.jo; +962 790334959

Abstract: In a natural and normal design process, combining art with science and technology and in the appropriate environments would with no doubt generates and provide effective and enduring products or solutions. While art may be considered an unnecessary extravagance value in designing a refuge shelter or tent (whether disasters or war refugees), science and technology is counted as substantial waste in an excessive cost when applied in harsh and rough environments and at short time and tight space. This paper aims at studying the possibility of conceptual designing an Ori-Nano-Refugee-Tent, which based on the idea of combining Origami as an Art with Nanomaterial as a technology and Architecture as a science. The research investigates, on the one hand the poor; aesthetic, utilization and critical conditions of the existing refugee structures, along with, on the other hand, the strong self-folding static dynamic techniques of the appealing artistic concepts of the Origami Art, and the added technical, operational and contextual attributes and values of the Nanotechnology applications. Introducing both Origami and Nanotechnology would respond to the changing human-environment needs to reach, a consensus between both the design principles of the Origami, which provides for multi folding forms and variable aesthetic structures, and the Nanotechnology, which provides durability, usability and controllability. The research resulted in proposing an experimental-conceptual Origami structure of Nanocellulose sheets operating with self-folding electrical activation current. The research needs further analytical, mathematical and laboratory investigation in order to reach the suitable Origami folding form and turning the idea into a real application.
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1. Introduction

Sheltering war and natural disasters' refugees is one of the urgent problems that stand out worldwide, for when people are struck by it there are no time to wait for solutions, solutions must be ready and at hand. More than 43 million people globally live as refugees or "internally displaced" (refugees within their own countries), 3.5 million of them live in cheap, canvas UN tents that start to collapse after about six months, which offer little comfort, dignity, or security. Further, the existing tents are cold in the winter and hot in the summer. They have no electricity or lighting, limiting refugee families' ability to lead a normal life.

As wars drag on in many countries in the Middle East and Central Asia, and as disaster-stricken areas as far as Haiti, people and organizations struggle to rebuild their homes and life's, the need for transitional shelter – something more than a tent but less permanent than a house – has never been greater. In recent years, many designers have turned up fantastic designs for semi-permanent houses, but few ever make it beyond the prototype phase. (sustainable-business/2014) They fail to tackle the unforgiving logistics of cost, weight and volume, not to mention the broader issues of land rights, local livelihood and cultural appropriateness. Furthermore, they disregarded the aesthetic appearance and physiological experience of those users who went through very harsh and difficult experiences, who wish for a place that could give them and their children some hope and optimism to live. Therefore, this paper is directed towards searching for practical and rational solutions of the problem of refugee habitats design, through investigating the possibility of combining Origami art folding techniques with Nanotechnology to produce a fully efficient self-folding "Ori-Nano refugee shelter" that can be folded as a small package and be easily distributed to refugees.

2. Facts, Impacts and Reasoning

In a study conducted by JU Architectural students, it concluded that while tents lack privacy and space, refugees camp lack private life and variety of spaces in and out. Tents features and image induce lack of opportunities to consider feelings of precedents, including fears, sadness and grief. It lacks windows, sun and daylight and darkness control, solid hard and soft flexile surfaces and faces. It lacks supply and drain, water, electricity and energy, sanitation and hygiene, weather control. In addition, it lacks satisfaction, security, endurance and happiness**.** Being a refugee by itself (people forced to leave home) has many impacts, yet staying in a refugee camp would aggravates all environmental, social, economic, mental-health and psychological impacts.

Figure (1) Expressive images of refugees needs of interactive space and experience (Adwan, 2015)

2.1 Environmental Impacts

The presence of large influxes of refugees has been associated with environmental impacts on land, water, natural resources and slum growth. Even when emergencies pass and refugees settled, although the nature of the environmental impacts change yet remain significant and that include; deforestation and firewood depletion, land degradation, unsustainable groundwater extraction and water pollution. Also, it slow land use practices associated with local progresses and developments. Such environmental impacts can also affect the long-term livelihood opportunities of both refugees and the host population. On the other hand, when refugees are able to access land or common property resources, their productive capacities tend to increase significantly. Correspondingly, in such cases, the burden of refugee presence on host communities and assistance providers tend to decrease as well. (Adwan, 2015)

2.2 Social Impacts

Many studies including UNHCR found that when refugees are from the same cultural and linguistic group as the local population, there are greater opportunities for peaceful co-existence and interaction among them. Yet gender based dominance including domestic violence, women trafficking and sexual abuse often increase during conflict results in displaced setting. Moreover, commonly complaints that refugees add to security problems in general and crime rates, theft murder and rape. Different ethnicity, however, can be a basis for problems. Traditional animosities may exist between groups. Even if it is not the case, failures in communication and understanding caused by language and or culture can form serious barriers. (Adwan, 2015)

2.3 Economic Impacts

Refugees presence leads to more substantial demands on natural resources, education and health facilities, energy, transportation, social services and employment. In any region, refugees' presence also can serve to catalyst the host region to development efforts that would otherwise never reach these marginal areas. While large scale presence of refugees invariably constitutes a heavy burden for receiving countries, they contribute to the creation of employment benefitting the locale population, directly or indirectly. An economic stimulus may be generated by the presence of refuges and can lead to the opening and development of the host regions, through: locale purchase of food and nonfood items; disbursements maid by aid workers; employment and income accrued to locale population through assistance projects for refugees' areas; the assets brought by the refugees themselves; shelter materials by agencies supplying relief items. (Adwan, 2015)

2.4 Psychological Impacts

How the person is received in the new country and how he meets and deals with the outer changes he or she is confronted in that country is the main experiences that would impacts his or her psychology. In leaving or fleeing a country and coming to another, the person experiences many psychological changes including: as an adult, his or her past homeland personal experiences, socioeconomic, natural or man-made catastrophes, traumatic experiences in relation to the previous, ability to return at any time to the homeland; as a child, he or she is identified with a state(s) of being of parents and siblings and going through all experiences in relation to that. Both an adult or a child passes many states of being; stranger, missing, lost, guilt and language degradation. In addition to self-estate of loneliness, guilt, shame, sorrow, longing and value degradation. (Adwan, 2015)

2.5 Mental-Health Impacts

Mental health issues are evaluated through length of time in the host country, circumstances of flight or travel, first asylum and who and what was lost. The symptoms that follow these impacts are grieving and depression associated with downward social status and inability to find work. Refugees are vulnerable to mental distress due to uprooting some adjustment difficulties in the resettlement country, such as language and cultural conflict and occupational problems. Culture may not only be the glue that holds a group together, it can also be their chief stressor in trying to adapt to new surrounding without losing their own identity or sense of self-worth. Uprooting creates cultural shock, a stress response to a new situation. There is a significant degree of mental stress during the first two years of resettlement; after three years, there is some improvement and increased adaptability. (Adwan, 2015)

3. Possibilities, Requirements and Cases

Although refugees' negative impacts conditions and situations, in general, exceed any positive variables or attributes that camps, tents or temporal refugee shelters can provide or solve, yet well-articulated camp and tent layout and design will with no doubt while reducing negative impacts will enhance positive ones and that include manipulating, time, materials, space and structure.

It has to provide fast assembly; immediate protection for dire situations; and easy transformable into other shapes. It has to permits for the occurrence of internal and external uses depending on individual's needs. To provide privacy, security and at the same time to permit interaction, integration and coexistence with the surrounding setting, milieu and social structure. It has to be of a high durability, dust and water proof that is to prevent water seething, clamps, puddles, molds, condensations and fungus, also slither and bug proof. It has to be one-component self-structure, with minimum joints, pieces or parts. To allow space articulations, definitions, addition and subtraction. To permit duality of actions; that is the possibility to open or to close openings, including windows or doors; to permit at the same time to prevent air movements and currents. To provide adequate lighting, shade and shadow and constant ventilation. Eco friendly with minimum ecological footprints and appropriate land carrying capacity. To stand weathering, live and dead weight and forces. To permit the interference of lightweight shelter that make them sturdier than the canvass structure. In short terms, it has to be enjoyable, flexible, durable, transferable and controllable.

3.1 Appropriate and Optimum

The wide range of variables of refugees' conditions and situations and the narrow tolerance in their constant needs and requirements, would envision at first glance a tent or any temporal shelter of a highly-sophisticated structure. Anyhow it is about bringing basics and sophistications into one constituent syntax. That is, it is about deploying basics of Origami art, with wonders of the Nanotechnology materials to develop the optimum-appropriate tent design.

3.2 Refugee Shelter Case studies

3.2.1 Ikea Refugee Shelter

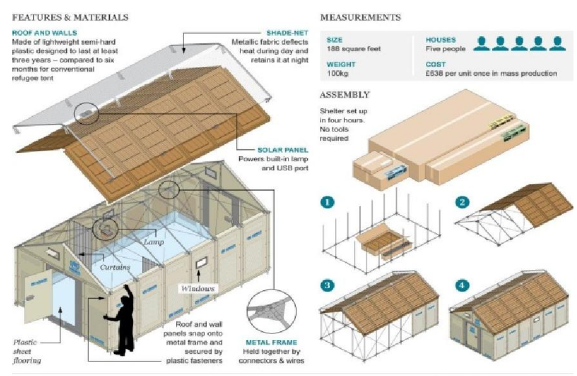

Figure (2): IKEA Refugee House / Source: http://cobish.com/news/shownews.php?id=82#.VJZl3V4Ai

IKEA turned its flat pack sensibilities from the urban apartment to the global village by unveiling a comfortable, solar-powered shelter that can provide emergency housing for natural disaster victims and refugees, figure (2). The flat pack homes were developed in collaboration between the IKEA Foundation and the United Nations High Commissioner for Refugees (UNCHR). (www.inhabitat.com) IKEA's shelters come flat packed, making for the easy transport of lightweight plastic shelters at once. Assembly of the 188-square foot hut is easy and can be built in just four hours. Five people can sleep comfortably inside, which is twice the size of the regulation refugee tent. The best part, the homes have solar paneled roofing, allowing inhabitants to generate their own electricity, extinguishing the need for candles or kerosene lamps. The roof also helps to deflect solar reflection by 70%, keeping the interior cool during the day and warmer at night (Boer, 2013).

3.2.2 Soe Ker Tie Bamboo Refugee Houses

There's nothing better than design with a cause, and that's exactly what the Soe Ker Tie Houses on the Thai Burmese border are. The project was developed with sustainability concepts in mind, and was created to house Karen refugee orphans. The purpose of the project was to allow 24 orphans within the village of Noh Bo a more normal life, with a home to call their own. These modest homes were constructed utilizing locally sourced bamboo, the roof was built with a design that promotes natural ventilation, and also allows surplus water to be collected when it rains, figure (3). This project is sustainable right down to the tire constructed foundations, also to ensure there would be no problems with moisture or decay, all of the huts are elevated above ground level (Slessor, 2009).

3.2.3 The Domo Shelter

Daniel Kerber has developed a shelter system that offers a flexible space and a more dignified home under canvas. "*A tent is very good to deliver short term relief. It's very lightweight and can be transported to any area of the world very quickly. But then the problems start*" says Daniel Kerber, the Berlin-based designer leading an organization called " more than shelters". His team has designed a new shelter system called Domo, figure (4). It is a tent-like shelter that is easy to set up and long-lasting. But unlike standard humanitarian-issue tents, the Domo is highly adaptable to climates and to people's needs. Kerber says the Domo concept is to focus more on the needs of refugees than simply serving the logistical needs of humanitarian agencies providing mass emergency shelters.

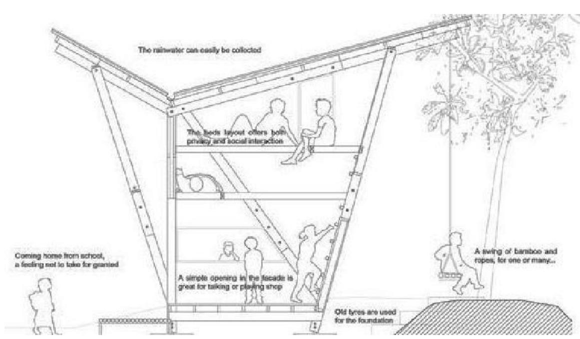

Figure (3): Soe Ker Tie Bamboo Refugee Houses / Source: http://inthralld.com/2012/03/soe-ker-tie-bamboo-houses-built-for-refugee-orphans/

The Domo shelter package is designed to weigh the same as a standard tent, approximately 50 kilograms. From the outside, the basic Domo resembles a big igloo in shape. It has six sides and is covered with a cotton shell. Inside the 25-square meter shelter, the ceiling is nearly three meters high, making it very comfortable to walk around.

The curved frame that forms a dome is made of six-fold out arms which can be made from, either plywood, metal or even recycled plastic. "*This is our main invention. We had to invent a very stable structure that pops out of nothing, the lattice-like fold-out arms allow two people to easily erect a Domo without any additional tools.*" says Kerber. Once you unfold it and lock it - you can do that within 10 seconds - you now have a huge diameter covered and if you put six of those together you have the room defined. And that's quite a big room that comes out of a box in a few minutes and is really stable.

Standard camp tents need to be replaced every six to eight months. However, the main structure of the Domo can last around 10 years - only the outer fabric needs to be replaced or upgraded according to climatic conditions. (http://www.dw.de)

As concluded from the previously discussed case studies, when considering emergency temporary housing the following measures revolve around the success of such shelter and relief efforts; structure; cost; availability; transport time; setup time; quality; durability; size; security; weather proof; design look; privacy; noise; cleanliness (Sadiqi and others, 2012). The discussed refugee housing designs may have succeeded in achieving some of the design measures mentioned above but definitely lacked much in terms of the following aspects:

- *Flexibility:* The maximum number of people is fixed to accommodate five people, which means that if any family exceeded this number, they will be separated into two units.

- *Aesthetic and quality*: The lack of consideration for the visual community characteristics in the unit's design.

- *Environmental concerns:* The design of the unit is not flexible enough to suit any type of environment, which in turn may lead to further disasters caused by harmful weather conditions.

- *Time and cost:* The construction process of these units is of high cost, and needs time and assistance, which opposes the fundamental concept of refugee housing.

- *Urban design:* The lack of attention for the outdoor urban spaces created by the units' arrangement, while these could be efficiently used to improve the quality of life of the dwellers.

- *Cultural varieties*: The design of the units does not take into account the social cultural distinctive characteristics of each area.

Reaching the ultimate design solution for refugee housing units and ensuring the good quality of life for the inhabitants based on the previous discussion, is not an easy straight-forward task. Refugee houses should be flexible enough to expand, fold, and unfold, be relatively light and easily built and structured. The basic principles of origami art hold all these ideas on a smaller scale, a scale of a paper! but a paper is too light, too flexible, hence too weak. Although this paper constitutes the main problem it can be nevertheless the ultimate solution! Therefore, the fields of origami and nanotechnology has been selected by the researcher to combine both fields to turn this paper into a folding house.

Figure (4): The Domo Shelter / Source: http: //www.dw.de/emergency-shelters-should-be-temporary-but-they-need-long-lasting-engineering/a-17801662

First, an overview of the principles of Origami art and folding techniques are investigated as the geometric form plays a great role in defining the behavior, structural strength, volume, space and dynamic properties of the house when folded and unfolded, then the principles of Nanoscience are introduced to benefit from that science and design our own sheet material.

4. What Origami is About

Origami is, transformation, combination and formulation of art with mathematics into engineering to form architecture. It is about art integrity and affordability, integrated in within all other disciplines and applications; deploy-ability of basics, simple and genuine art into complex forms. Recent developments due to computational tools and improved understanding of its mathematics; Origami became; an active field of mathematics; a surface geometrical generator (Gaussian Curvatures); a concept initiator of endless mathematical possibilities and variables of foldability (flat & rigid). Engineering of variety of applications using self-efficient and self-sufficient structure; design deployable foldability of embedded structures; from one input surface plate generating several structures output. Origami endow architectural form with; a visual appeal; kinematic folded plate structures; strength of materiality image; plenty of challenges to explore; clear lines and edges gives stiffness of durability and sustainability. To be able to design an architectural structure with origami, three main issues carefully needed to be considered; first is the right folding pattern that can produce the right form for the specified need; second a technique through which the structure can be deployed from a two-dimensional sheet to a three-dimensional structure and vice versa; last but not least the right material that can be folded and undertake the load without breaking - that is to be stiff, flexible and stable.

4.1 Timeless Art for Temporal Material

In the field of Origami, it is investigated how to design different shapes only from one sheet of paper using folding techniques. In the folding technique, single planar material folded without stretching, tearing or cutting. This theoretical definition of folding technique exists only in geometrical and mathematical context using ideal zero-thickness. If we consider material thickness and stiffness for large-scale space structures, stretching and tearing inevitably appear in the construction. (Stavric & Wiltsche, 2013) Therefore, the choice of materials pays a great deal when designing large folded structures.

In our contemporary time with all the revolutionary technologies appearing in all fields of science and art, it is now possible to fully unleash the limits of architects' imagination, and give them a boost in design thinking that allows for new revolutionary design variations. It is always magical when science and art meet.

4.2 Pro-Properties Potentials: Origami types and applications may be considered an added value to materials by; increasing its stiffness; enhancing its deploy-ability; growing its energy-efficiency; intensifying its impact-absorption; developing its meta-material properties, including its image-ability, richness, robustness, legibility and values.

Objectives

Problems in tent	Solution	Origami
Organizing the camps district	Distribute the functions clearly	Has to have clear outlines and well-controlled sizes
Creating clear zones	Organize the functions clearly	Easily dealt with in regard of function transformation.
Materials durability	Nanotechnology	Structure : galvanized metal Membrane : plywood, tensile fabric & cardboard
Providing adequate lighting methods	Skylights – glass coating	Leave openings to install glass for the sake of ventilation and sunlight.
Constant ventilation	Slighting windows- exhaust fans.	Leave horizontal hatches to install heating furnaces.
Preventing solid dusts from entering the tent	Utilizing solid doors & window screens.	Leave openings for doors and windows.
Preventing water from seething inside.	Elevate the tent from the ground level plus Nano-tech.	Using well-insulated materials.

5. Origami Self-Folding Techniques

5.1 Self-Folding through Electrical Currents

In 2010, certain studies developed a method where a sheet of composite material can self-fold when an electrical current is passed through it. This study worked on planning and controlling algorithms that enable a programmable sheet to realize different shapes by autonomous folding. This approach exploits a single sheet composed of interconnected triangular sections. The sheet is able to fold into a set of predetermined shapes using embedded actuation (motors), figure (5). When an electric current is passed through the sheet, selected edges expand and/or contract causing the sheet to fold into origami-like boats & planes, figures (6). Once the desired shape is realized, the shape is held in place with magnets. This seemingly simple procedure is significant because it requires that a material interacts with its environment and rearrange itself according to specified shapes/stiffness. (Byoungkwon& Others, 2010)

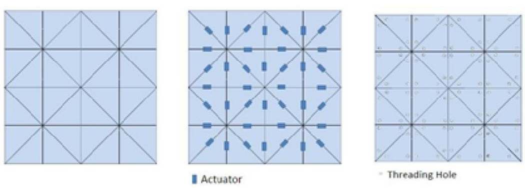

Figure (5): A 4*4 box-pleated sheet (left), with edge actuates (motors) (middle), and threading holes (right) Source: (Byoungkwon & Others, 2010)

5.2 Self-folding through Light Exposure

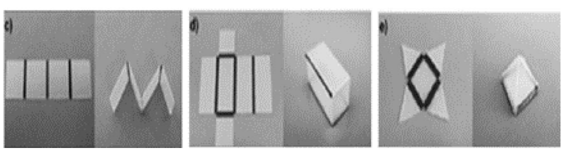
Figure (6): polymer sheet polyhedral self-fold when exposed to light. / Source: (Liu & Others, 2011)

5.3 Self-folding through Water-Ink Printing

In 2012, it gets even easier! Self-folding origami is made possible with a mix of water & ink printed on paper, figure (11). Industrial Design student, Christophe Guberan, from Ecole Cantonale d'art de Lausanne was able to make a sheet of paper self-fold when water/ink is printed on the paper. The printer is fitted with a special mix of water and ink. As the water/ink mixture dries, it causes the paper to buckle and fold along the printed crease lines thereby transforming a 2D sheet of paper sheet into a 3D structure with volume. The process is as simple as 1-2-3:

-Design the crease pattern on a computer.

-Print the pattern on a sheet of tracing paper.

-Watch the paper fold itself along the crease lines.

In 2011, this process was made easier when it was able to get a polymer sheets to self-fold when exposed to light. Michael Dickey from North Carolina State University developed a technique where polymer sheets self-fold when exposed to light, figure (6). Polymer sheets were run through a desktop printer to get a pattern of black lines (crease pattern). When the polymer sheets are exposed to light, they automatically fold along the black lines. (Liu & Others, 2011) The idea is this: black absorbs more energy than pale colors so the black lines will shrink faster than the surrounding white areas. You can change the angle of the fold by changing the width of the black lines. You can achieve valley or mountain folds by printing the lines on the top or bottom side of the polymer sheet.


Figure (7): water- ink printed folding / Source: http://www.origami-resource-center.com/origami-science.html#hawkes

As noticed from the previous discussion, Origami Art has all the conceptual, theoretical and structural principles that can enhance the design of a refugee house. The folding patterns will enable us to design a housing units that are foldable, structurally stable, with light weight and easy to transfer. The only obstacle for origami to be incorporated into architecture is its material condition of having to be thin and flexible enough to fold! Nanoscience is the solution to provide origami with just the right material that can turn folds into efficient architectural structures starting with refugee housing.

6. Quantum Technology for Eternal Materials

Advanced Technologies like Nanotechnology are emerging and developing with every passing day, as they offer solutions to the upcoming world problems and make the world a better place to inhabit. Nanotechnology is a rising field of science that is related to the matter at the nanoscale; at dimensions between 1 and 100 nm (Birgisson, Mukhopadhyay, Geary, Khan, & Sobolev, 2012). The Royal Society and The Royal Academy of Engineering published a report in 2004 that includes the common definition of Nanoscience and Nanotechnologies; Nanoscience '*is the study of phenomena and manipulation of materials at atomic, molecular and macromolecular scales, where properties differ significantly from those at a larger scale'*, it is a 'horizontal-integrating interdisciplinary science', which means that it involves concepts of more than one discipline, such as chemistry, physics, etc. (Filipponi & Sutherland, 2012).

Therefore, "Nanotechnology" as a term, *is the design, characterization, production and application of structures, devices and systems by controlling shape and size at the nanometre scale.* (The Royal Society and the Royal Academy of Engineering, 2004) (Filipponi & Sutherland, 2012) (Maynard, 2007). Including, durability, sustainability and recyclability.

7. What nanotechnology is about

Molecular nanotechnology is an engineering discipline in which the goal is to build devices and structures that have every atom in the proper place. By means of this general purpose material-processing technology it will be possible to build almost any rigid, covalently bonded structure. Identical parts will be truly identical, enabling energy conversion and computation systems to have extremely high performance and reliability. Assembly will be done by mechano synthesis, the process of holding two reactive molecules in contact with each other in a controlled orientation. Synthesis will be done on nanoscale assembly lines called molecular mills, where systems of moving belts will press individual molecules together and catalyze 106 reactions/s per station. High-performance mechanical computers will use moving rods to block the motion of other rods. The most important physical limit will be radiation damage. Without redundancy, a subsystem lasting 100 years will be limited to 106 nm3.

8. Art-Technology in Quantum Material Properties

Embedding technology in art or vice versa, was one of the main creative thinking processes refer to by designers whether in ancient or modern time. Nano-technology and Origami-art are two wonderful concepts that can create novel creations. When combined together they can produce even more creations that are significantly more intelligent. Combining the ability to manipulate matter at the scale of less than one billionth of a meter has the potential to transform the built environment in ways almost unimaginable. Nanotechnology can take building enclosure materials (coatings, panels and insulation) to dramatic new levels of performance in terms of structure, energy, light, security and intelligence. Using efficient nanomaterial with origami folding might be just the right solution to create whatever structure or architecture, once seemed impossible. While architecture, structure or construction serves human physical, psychological, emotional and mental needs and that includes and cover his behavioral activities and experiences, technology, systems or tools work beyond and above human manual abilities and productivities.

What technology afford beyond human abilities and productivities are; Precision or Meticulousness; Fast and Speed; Effort and Power; Duration and Continuation; Details and Specific; Durability and Endurance.

9. Conclusions& Recommendations

9.1 Ori-Nano Refugee House proposal

The tent proposal is basically a folding house that one receives, as he receives a food package, built within minutes taken only to unfold it. It has a cheerful new look that might seem nicer and more comfortable than the house one has lost, warm, secure and comfortable.

As concluded from the needs and aspirations of refugee housing design around the world, the deep understanding of the principles of origami art and the potentials of Nano materials, the combination of the three fields is possible. Each field offers something to the idea of "Ori-Nano Refugee Tent" to turn the conceptual thought into a real application.

Origami art not only provides a continuous structural pattern but also creates beautiful forms that add aesthetic values to the produced space, it enriches the use of the house and the experience of the user. The folding geometry to be selected can be one that offers multiple forms when unfolded; for example, it could have the option of controlling the degree of interaction between the indoor and the outdoor. The multiple options of folding can also be designed to have the housing units connect with one another, thus forming a more complex housing structure or neighborhood. This adds a social value to the design for it contributes in strengthening family and community bonding along with increasing the level of security.

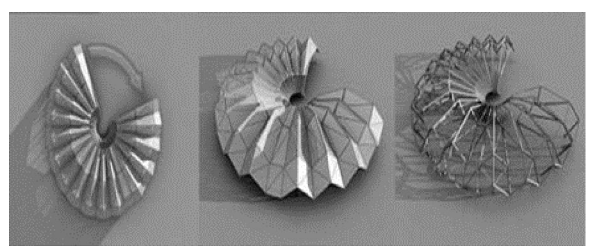

Figure (9): a demonstration of how sheet materials like paper can act as both the structure and the skin if it had strong and flexible properties. / Source: http://inhabitat.com/origami-inspired-folding-bamboo-house-by-ming-trang

The world is entering the sphere of Nano. Nano has a potential to become the flagship of the new millennium's building method and architectural style. New materials are being discovered and developed, these new materials present new opportunities to solve problems, what we are aiming at for the Ori-Nano Refugee Tent is a skin structure, which with the help of nanotechnology it would conform into sheet or plate material that has the following properties:

1. The strength of steel to bare its own weight, withstand and endure weather conditions.
2. The lightness and flexibility of fabric to have easier folding and packaging, hence easier and cost efficient transportation and distribution.
3. The thermal properties of concrete to store heat at day and emit it at night.
4. The ability to control its transparency and ventilation levels to permit the needed amount of air and light interactively with the environment and the user; the material would have the ability to sense the temperature of the inside and increase or decrease its transparency level responsively in certain areas (that don't threaten user privacy) until the inside temperature level reaches to the comfort zone of the human being.
5. Good insulation properties.

The ability to capture solar radiation to produce and store electricity to use in the inside and to light the house skin at night, this helps in keeping the area lit and secure and gives a cheerful look to the refugee camp.

9.2 Suggested Folding Pattern, Deployment technique and Nano-material

To be able to design the Nano-Folding Refugee Tent, three main issues need to be carefully considered; the first is the right folding pattern that can produce the right form for the specified need, secondly the technique through which the structure can be deployed from a two-dimensional sheet to a three-dimensional structure and vice versa, and last but not least the right material that can be folded without breaking, that is, to undertake the load, be stiff and stable.

9.3 The folding pattern

This research investigated the basic folding patterns through evaluating each of them upon their efficiency towards achieving the refugee tent design requirements'; each basic folding pattern has positive and negative attributes concluded from the evaluation table (Figure.10) as follows:

9.3.1- *Yoshimura Pattern (Diamond Pattern)*: a rolled-up sheet from concave to convex, it offers different formal potentials, domes, stars and different other shapes. The final unit formed by folded diamond pattern will gather the rain water on the top and cause negative impacts on the roof top. The design is also not flexible enough to change its shape. On the other hand, the form is structurally stable, and from the inside it gives a clear functional space for a sheltering unit.

9.3.2- Diagonal Pattern: closely related to *Yoshimura Pattern*, but the form enables water gathering from the roof in an efficient way, gives clear indoor functional space, and offers a tremendous number of units' formations.

9.3.3- *Miura Ori Pattern (Herringbone Pattern):* has an axial crease with a secondary crease reflected across it. A flat sheet compressed. The formation of the pattern eases the process of water gathering and falling from the top instead of being gathered on the top. Solar panels can also be efficiently installed on the top to gather sunlight, but the main problem is that the indoor space formed by the patterns is not efficient enough to house every day functions.

Each simple folding pattern offers different potentials but at the same time, it has negatives related to important design aspect, therefore it's suggested that a combination of simple folding patterns is the right solution for a refugee tent design. To be able to find and determine the right hybrid pattern thorough studies need to be investigated in order to be able to explore multiple structures and forms, which can be then achieved by computational 3d simulation software's such as Rhino and Origamizer.

9.4 Deployment technique, Self-folding through electrical currents

Figure (11) shows the evaluation that has been done to the three self-folding techniques -Electrical current, light exposure and water-ink printing- upon their efficiency level to satisfy the refugee housing needs concluded from the previous study of the refugee tent design.

Unlike the electrical current deployment technique, the light exposure technique and the water-ink technique have a lot of limitations related to controlling the foldability of the pattern and the resistance to weather conditions for they highly depend on having certain amounts of light or air to have them fully unfold. Therefore, unless we provide artificial controlled light, heat and air – which adds up to their cost - their efficiency will fail.

The evaluation results highly recommend to explore the "self-folding through electrical currents" technique, for this technique enables controlling the deployment of the folds, hence give the user the freedom of controlling the openings of his house which means controlling ventilation, lighting and privacy levels. Not to mention the flexibility it gives for the deployment of multiple folds when needing to expand the housing unit.

The limitations of this technique lie only in the cost and the ability to generate electricity for each house, this can be easily solved if the folding material had PV cells. If electricity can be generated from renewable resources depending on the surrounding context of the housing development, the process of folding houses will be controllable and faster to set up more than in any other deployment system, once you get the electrical current the foldable sheet material will turn into a structure.

We can also think about the flexibility of the design itself, the sheet material can be manufactured to save in its memory more than one folding pattern that interacts with electricity according to the intensity of the electric current, which solves the problem of expanded units, and keeps the family in one place instead of being separated in two units again. Even when thinking on the larger scale, the arrangement of the tents will be controlled in a better way, as the electricity system is installed before even building the tent. Each foldable unit will have a defined place before being distributed to the refugees which leads to well-designed urban context and outdoor spaces.

The cost of folding units with electrical currents might be high; it may also face some serious safety and technical issues and lead to problems. But with the development of its manufacturing all over the world in mass production the cost problem could be solved.

9.5 Nanocellulose as a Sheet Material

Table (Figure 12) shows the evaluation of different materials with characteristics matching those required for the refugee housing building skin. Each material has a different efficiency level in terms of strength, Translucency, thermal conductivity, electrical conductivity, flexibility, weight, and so on. The aim is to produce an unprecedented material with all needed characteristics in full efficiency. Nanotechnology can achieve this for it can improve properties of material and combine different characteristics such as, light weight, high strength, low thermal conductivity, high flexible and stretchable, and translucency in one material or maybe more than one, and create candidate materials that fulfils refugee's needs.

From table (Figure 12) we can conclude that Nanocellulose can be the perfect choice for the sheet material to be used as a structural skin for the Nano-folding refugee tent because of its strength, flexibility, electrical and thermal conductivity, non-toxic. It is the most abundant polymer on earth in addition to its great development potentials at the Nano scale to be produced as a sheet material.

What is Nanocellulose? Why we choose this material? Nanocellulose could be used in folding the refugee tent because of its interesting mechanical properties for use in material applications; nanocellulose is a material derived from wood fibers, it has exceptional strength characteristics on a par with Kevlar, a lightweight material used to manufacture high-strength, durable materials, in purely physical terms, nanocellulose boasts of a whopping 8 times better strength-to-weight ratio than steel. However, in contrast to Kevlar and other materials based on fossil fuels, nanocellulose is completely renewable (Dieter, 2011).

Nanocellulose uses inorganic, organic and polymer materials to form physicochemical compounds. This makes it extremely interesting for the construction material industry as a reinforcement material for the manufacture of high strength polymer compounds with similar strength properties to those of metallic components. Nanocellulose can also be used to improve the mechanical quality of wood and cardboard materials. As Nano-porous bio-foams they can replace conventional insulation materials. It replaces the aluminum that is presently used. (Allan, 2011) The Forest Products Laboratory is supporting a project at the Army Research Laboratory in Aberdeen, MD to produce and evaluate primarily clear composites as reinforced glass. (Biopactcentre website, 2014)

Refugees Needs	Electrical Current	Light Exposure	Water-Ink Printing
1. Environmental: indoor quality			
1.1. Thermal Conductivity	⊖	⊖	⊖
1.2. Humidity	⊖	⊖	⊖
1.3. Natural light & Ventilation			
1.3.1. Openings	●	◐	◔
1.3.2. Translucency	⊖	⊖	⊖
1.4. Electrical Conductivity	●	⊖	⊖
2. Safety			
2.1. Structural Strength	⊖	⊖	⊖
2.2. Healthy= ex. Anti-Bacterial	⊖	⊖	⊖
2.3. weather proof	⊖	⊖	⊖
3. Aesthetically pleasing (cheerful)	⊖	⊖	⊖
4. Flexibility	●	◐	◔
5. Cultural			
5.1. Variation in shape and colors	⊖	⊖	⊖
5.2. Privacy	⊖	⊖	⊖
6. Social: Space efficiency			
6.1. Expandability = Stretchable	●	◔	◔
6.2. Interior partition	●	◔	◔
7. Sustainable			
7.1. cost efficient	⊖	◔	◐
7.2 set-up time	◕	◐	◕
7.3 durable	◕	◐	◔
7.4. energy efficient 7.4.1. water harvesting	⊖	⊖	⊖
7.4.2. water purification	⊖	⊖	⊖
7.4.3.energy generation	⊖	⊖	⊖
7.5. Light Weight	⊖	⊖	⊖

Effeciency Level Code: No Relation 25% 50% 75% 100%

Figure (10): Origami Folding Patterns Evaluation / Source: Author

Nanocellulose, in addition to its incredible strength, is also thermally stable, it has low coefficient of thermal expansion. Nanocellulose is considered to be an easy applicable insulator. Several layers with the same or different compositions can be combined together into the final multilayer structure during forming (Harmer, Liauw, Scialdone, & Kang, 2012).

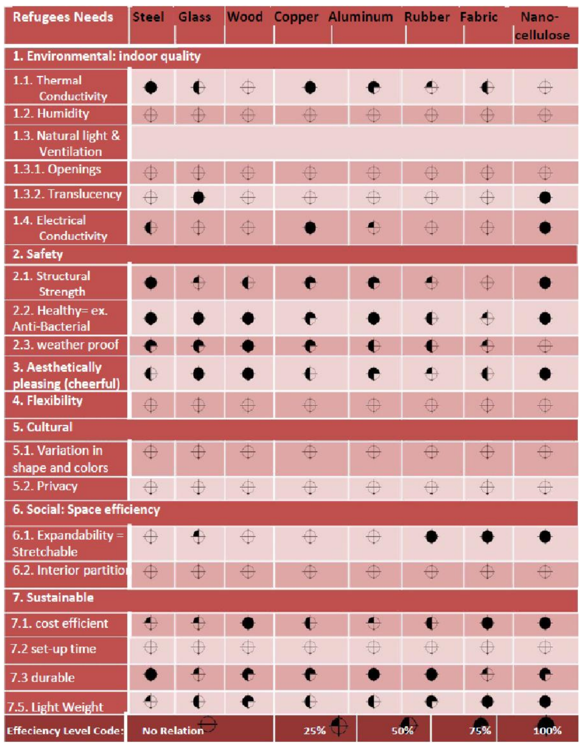

Figure (12): Materials Evaluation / Source: Author

coating, packages and building materials. Therefore, Nanocellulose can be the perfect choice for the sheet material to be used as a structural skin for the Nano-folding refugee tent.

Nanocellulose has the potential to be processed on an industrial scale at low cost lower than other nanomaterials. Moreover, Nanocellulose paste can be flexibly shaped, or used to laminate other surface, and when it dries, it has amazing properties. Nanocellulose is also very similar to glass fiber or Kevlar, for the crystalline form of nanocellulose is transparent (Thakur, 2014).

Cellulose-based nanofibres can be used to alter the structure of materials and create products that better correspond to future market needs. Nanofibers can be released from cellulose by a range of conversion technologies: acid hydrolysis, multiple mechanical shearing or enzymatic hydrolysis.

Nanofibrils provide a number of possibilities for treating wood fiber materials and adding completely new properties to them. The mechanical properties of raw materials can be improved, their moisture behavior controlled, electrical properties changed or optical properties adjusted. Applications of Nano fibrils include special papers, paper.

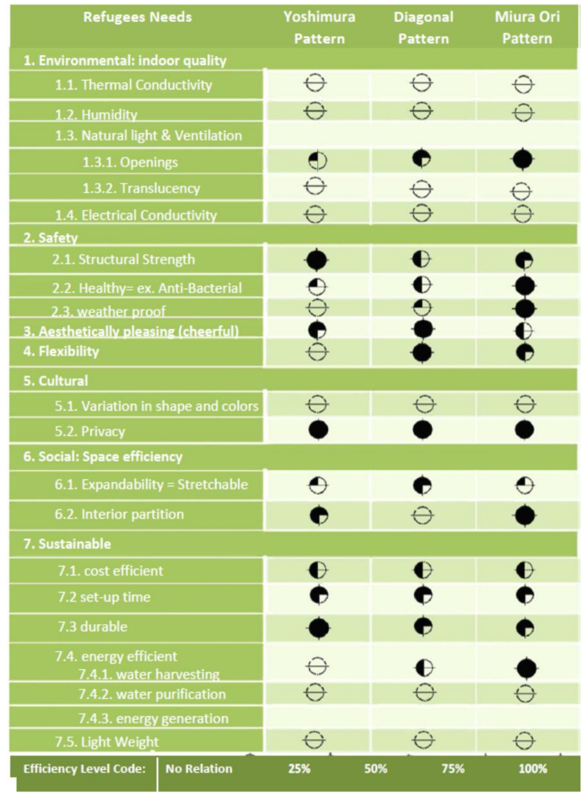

Figure (11): Self-Folding Techniques Evaluation / Source: Author

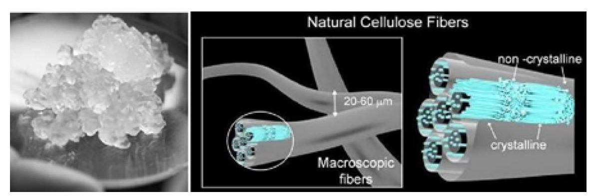

Figure (13): Natural Cellulose Fibers. / Reference: www.innventia.com/en/Our-Expertise/New-materials/Nanocellulose/

Corresponding Author:
Dr, Omar Musa Amireh
Department of Architecture
School of Engineering, University of Jordan
Queen Rania Street, Amman Jordan
Tel +962 790334959
E-mail omaamir@msn.com

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