POP-UP TECHNIQUE OF ORIGAMIC ARCHITECTURE FOR POST-DISASTER EMERGENCY SHELTERS

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Abstract

This paper presents a pop-up technique based on origamic architecture as a technological design solution for post-disaster temporary shelter systems. First of all, the concepts of disaster and post-disaster are briefly introduced, and the roles and needs of post-disaster temporary shelter systems, particularly in emergency periods, are reviewed. Second, pop-up techniques based on origamic architecture are briefly discussed. Third, a formal language for opening the cards of origamic architecture is introduced, out of which a geometric elasticity has been developed. With the language, a variety of flexible and expandable designs for shelter structures can be generated by incorporating different pop-up techniques. Finally, a prototype shelter has been constructed to demonstrate the adaptability and sustainability of the shelter within the local environment and the affected society, considering portability, low-cost, and easy in assembling by any unskilled person.

Keywords: *Origamic Architecture, Pop-up Technique, Deployable Structure, Temporary Shelter, Post-Disaster.*

INTRODUCTION

The term 'disaster' connotes large scale losses of life, the destruction of property and habitation, a wide range of injury and illness, and the displacement of large numbers of people. In other words, a disaster is a situation of extreme (usually irremediable) devastation that causes the collapse of the social fabric. Accordingly, the affected community is unable to cope with the disaster and external assistance is often required (Rautela, 2006). While many attempts have been made to define disasters, the Center for Research on the Epidemiology of Disasters (CRED) presents a clearer definition of the term as "a situation or event which overwhelms local capacity, necessitating a request to a national or international level for external assistance; an unforeseen and often sudden event that causes great damage, destruction and human suffering" (CRED, undated). There are principally two types of disaster: (i) natural disaster, which includes hydro-meteorological disasters (floods and wave surges, storms, droughts, forest/scrub fires, landslides and avalanches), geophysical disasters (earthquakes, tsunamis and volcanic eruptions) and biological disasters (epidemics and insect infestations) (EM-DAT, 2004), and (ii) man-made disaster, which includes conflict (clash, war, violence, riot, and terrorism), technological failure (dam failure, industrial, fire, mining, and pollution) and so-called complex emergencies (sometimes natural disaster or the combination of both natural and man-made disaster also causes famine).

Apart from taking a mass number of lives, disasters further impact the situation by destroying inhabitation and social and economical structures on a catastrophic scale. Although various efforts have been carried out to reduce disasters and damage during the last decade, data (accumulated by ISDR-International Strategy for Disaster Reduction) on post-disaster impacts regarding the loss of lives, injuries, and economical damages from 1991 to 2005 reveal a failure to reduce natural disasters and related damage. Moreover, post-disaster environmental impact of generating debris and rubble makes the affected region unlivable, creating aquatic and terrestrial pollution, and resulting in soil contamination and salt and sand intrusion of water sources. This vulnerable situation is exacerbated when victims begin to suffer the impact of these conditions, physically and psychologically. Such a state is referred to as a humanitarian disas-

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ter (UNEP, 2005). It may take several months to years to recover from this situation. During this phase, victims have an urgent need of shelter, which should play the role of protection rather than an emergency object such as a tent (Babister and Kelman, 2002).

Based on the period of recovery and resettlement for a displaced community, post-disaster shelters are categorized as emergency (or temporary), transitional, or permanent shelters. Whereas a temporary shelter entails the sheltering or protecting of victims during an emergency situation through the provision of basic living facilities, a permanent shelter entails reconstruction of the livelihood and accommodation of victims for a sustained period. A transitional shelter is provided for victims during the period after recovering from the emergency situation until they can return to permanent accommodation.

Throughout the relief process, the efficient coordination of the different stakeholders' efforts from various bodies including local and national government, the army, NGOs (None Governmental Organizations), etc. is needed for the successful provision of aid to the victims. In particular, the primary objective of temporary shelter for the emergency period is to provide adequate shelter to victims who are deprived of the essential needs of life following a disaster or conflict until they can be accommodated in transitional or permanent shelters. Aside from recovering from post-disaster fear and damage, the affected community seeks to continue life as it was before as soon as possible.

After conducting onsite and offsite investigations on sheltering systems and settlements to uncover the inherent sources of crises in the affected community, Davis (1978) recognized that "… shelter must be considered as a process, not an object." The process specifies the reformation of social, cultural, and economical structures with the mitigation of post-disaster hazards, and management of aid to victims. The other reason that may cause failure of the post-disaster sheltering system lies in ignorance of the harmony of cultures and social structures while designing transitional, permanent, and especially emergency settlements, as Schilderman (2004) noted. By focusing on the very meaning of 'recovery', Wisner and Walker (2006) have identified the failure of reconstruction in terms of 'accountability, transparency, and the unevenness' with which the international community responds to crises.

Architects such as Nader Khalili and Shigeru Ban have proposed a number of post-disaster sustainable structures by considering socio-cultural aspects of the affected community. A team from Istanbul Technical University developed the "Urban m3 - Respect for Life Project" in 2000 based on research findings on bringing livelihood to dislocated communities due to a massive earthquake in Turkey in 1999. This project offered an alternative design solution that provides not only environmental protection and disaster mitigation but also a high level of socio-cultural satisfaction (Saglamer, et al., 2006). Nevertheless, most of these approaches are tailored to post-emergency periods or transitional settlement, whereas relatively little work has focused on the emergency period - the time immediately after being struck by a natural disaster or conflict when victims are more desperately seeking rapid recovery.

1.1. Temporary Shelters

There are two different approaches to sheltering the victims temporarily in a post-disaster emergency period. One is in-situ construction of temporary buildings that is carried out on the building site using raw materials with the intention of transforming the structure into permanent accommodation. The other is a kit-supply, which consists of a prefabricated temporary building structure including basic survival needs such as food, water, and sanitation and immediate medical assistance facilities. Undamaged buildings (especially institutional buildings) are at times converted to temporary living place for groups of affected families; however, this system is not feasible for a mass number of victims. Although in-situ construction systems are more durable and desirable for victims than kit-supply packages, a large number of in-situ constructions are not be possible within a few days just after the immediate natural disaster. Furthermore, in-situ construction, which usually also aims for transformation into a permanent structure, requires sustainable planning and strategic arrangement of shelter structures in accordance with the national or regional planned framework developed by a team of policy makers, planners, architects, and the local

community. It may take a few days to months to implement this planning on-site during the disaster emergency period.

Temporary and quickly deployable prefabricated shelter structures are employed in the emergency period with the intention that the shelter can be reutilized for transitional and permanent structures. For this, the erection of temporary shelters should not only be limited for disaster victims in major disasters or emergencies but also for other emergency programs, such as education, health, child care, post-trauma counseling, relief-materials distribution, and so on. The general basic pros and cons of in-situ solutions and that of kit-supply solutions with regard to sheltering in a post-disaster emergency period are as shown below:

1.2. Aim and Scope

After a disaster strikes, the foremost physical loss of survivors is their home, which provides security, privacy, and human dignity. It is a physical base within which they live, and a physical component upon which a community is formed. The presence and arrangement of these physical components, i.e., homes and other buildings, determine the social infrastructure and social environment of a society. Accordingly, a relationship among infrastructure, environment, and livelihood exists in a community and preserves the tradition and culture of the society. When a disaster occurs, this relationship can readily collapse, thus destroying the social structure of the affected community. Hence, a new relationship among those three components should be reestablished in order to reform the social structure of the community, a process that includes both sheltering and settlement.

Although a shelter structure should be constructed immediately, as one of the fundamental physical elements of sheltering and settlement processes it must be 'a habitable covered living space, providing a secure, healthy living environment with privacy and dignity to those within it' (Foster and Fowler, 2003). During the post-disaster period, the emergency settlement process requires fulfilling the needs of those who have lost their home with the most appropriate type of response (Babister and Kelman, 2002). In this regard, the first need is a home, some sort of dwelling-shelter. Shelters for recovery and social programs, based on which the sheltering and resettlement processes will be carried out, should thereafter be established.

The present study focuses on the physical element of the sheltering and settlement process, i.e., on the structural shelter item. By identifying the problems of post-disaster (and post-conflict) reconstruction and rehabilitation as discussed earlier, this paper has initially attempted to point out the responsibilities and roles of the structural shelter that directly or indirectly influence the post-disaster (and post-conflict) resettlement process and social structure. The scope of this paper is limited to a technological design solution for an emergency shelter structure that provides spatial and formal structural contributions to the immediate post-disaster resettlement and reconstruction processes. Specifically, a pop-up technique of origami architecture is suggested. The technique is used to erect the structure rapidly and efficiently with various geometric possibilities, thus creating a variety of needed spaces.

The shelter design offers flexibility and expandability so that victims can customize their dwellings to suit their needs and express their values. Those who will live in a space need to be involved in its planning, and also the building needs to be able to accommodate unforeseeable events (Habraken, 1972 [1961]). However, poor quality and higher costs of the shelters, and disputes and loss of deci-

In-Situ Emergency Shelter	Kit-Supplied/Deployable Shelter
• Construction from local materials	• Usually tent, made from canvas and supported by metal or wooden poles
• Low cost	• Sometimes folding or modular; costly
• More durable	• Less durable
• Slow process	• Easy and rapid construction
• Need skilled person(s)	• No need of skilled persons

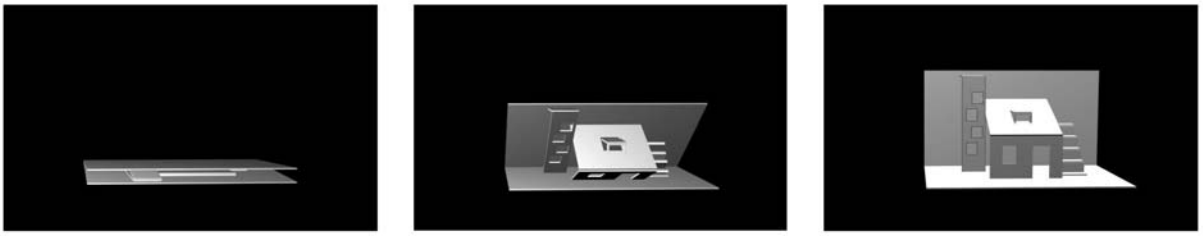


Fig 1. Origamic architecture when the card is closed, half-open, or opened (from left to right)

sion flexibility among disaster relief organizations, manufacturers, designers, constructors, suppliers, distributors, and users should be avoided in the process of producing the system (Kendall and Teicher, 1999). Furthermore, the use of local or universal, durable, sustainable, and reusable materials should be considered. Lightweight, cheap materials, insulated panels, and simple deployable systems should also be considered to make the shelter portable, economical, weather resistant, and easy to erect by any unskilled person.

2. ORIGAMIC ARCHITECTURE AND POP-UP TECHNIQUE

Origamic architecture is the art of paper folding where buildings are reproduced by paper folding in cards. When a card is opened, the reproduced building is erected immediately (Figure 1). The secret behind the immediate erection of a three-dimensionally mimicked building from a two-dimensional card in origamic architecture lies in the pop-up technique. In this technique, a small number of different folds are used according to the desired product by making creases on flat paper. Apart from reproducing buildings in origami art, a number of geometric patterns and everyday objects can also be produced on various scales (Chatani, 1984).

If the origamic architecture system is imagined on a large scale, i.e., the scale of actual buildings, then the possibility of constructing a house or a building within a few minutes can readily be considered. Such a system could be practically adopted for small scale structures such as shelters and also for large buildings having a modular structure. This system was applied in practice for the first time to make deployable large solar panel arrays for space satellites, and is known as the 'Miura Map Fold' (Miura, et al., 1980). In this project, paper was replaced by a metal sheet and hinges were employed in lieu of creases. This type of origami is known as Mura's 'rigid origami'. This concept has been applied to our pop-up origamic architecture technique for realization of post-disaster shelters, where immediate construction of shelters and multiple spaces for various programs regarding post-disaster situations are needed. Among various techniques, folding, sliding, scissor, and rolling systems in origamic architecture are considered in terms of how to erect a three-dimensional paper model from a two-dimensional unfolded card.

2.1. Folding System

The most common pop-up technique in origamic architecture is folding systems. In this system, first, folding lines or creases are drawn on a paper

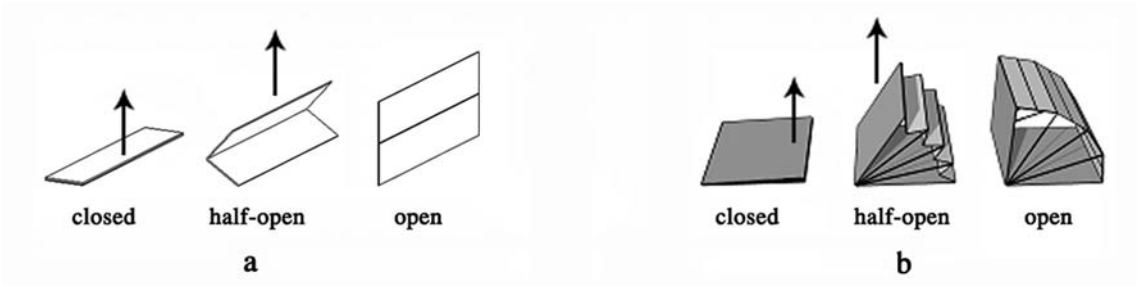


Fig 2. a - Folding system, b - Pop-up of a card by using folding system

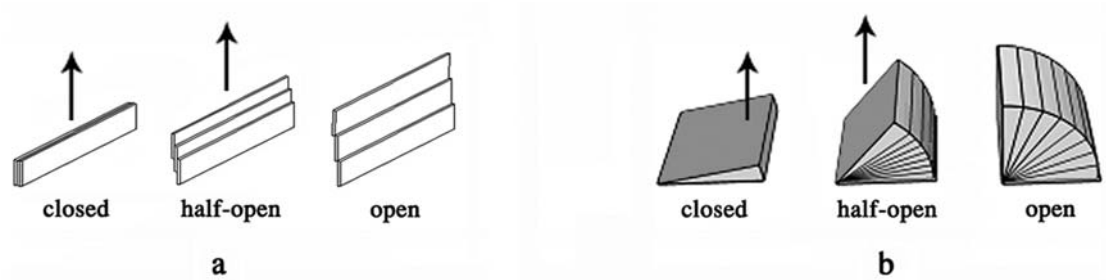


Fig 3. a - Sliding system, b - Pop-up of a card by using sliding system

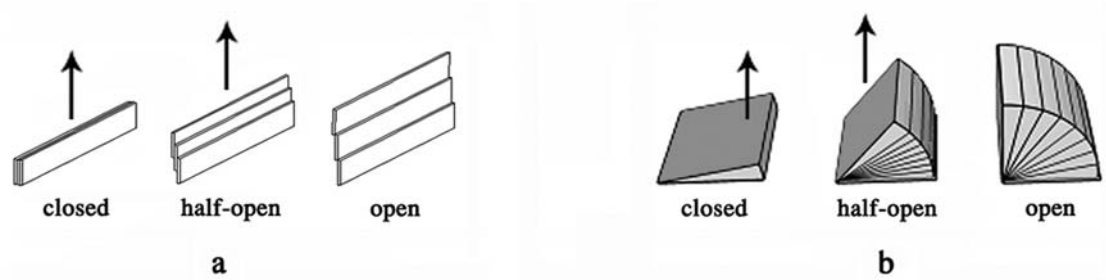


Fig 4. a - Scissor system, b - Pop-up of a card produced using the scissor system

according to the design of the desired product or building before unfolding the card. The paper is then cut-out by following the creases and folds or, without cutting, the paper is directly folded inside the card following the creases. When the card is opened, the folded paper pops up to make the desired product or building (Figure 2a). A folding system adopted in a card, opened 90o vertically, is shown in Figure 2b.

2.2. Sliding System

In a sliding system, similar panels are stacked together one on top of another. When one of any end panel is pulled, each panel starts to move over the surface of its lower panel while maintaining smooth continuous contact, thus covering a large space (Figure 3a). In the case of applying this system to a card, opened 90o vertically, similar channel-shaped panels with triangular ends are placed together one on top of another on a plane by keeping the open ends fixed concentrically (Figure 3b). When the card is opened, panels start to slide up to form a three-dimensional volume.

2.3. Scissor System

Scissor rods in a scissor system are hinged at the middle and their corresponding side ends are connected to a single bar along which the ends can move freely. Thus, a number of scissor units are connected with bars to form a network. When one end of the network is pulled, it starts to elongate, covering a larger space (Figure 4a). The scissors act as a frame when they are applied to a card opened 90o vertically. When the card is closed, the scissors are laid on one line at the edges of the card. However, while opening the card, the scissor rods start to erect, thus producing a frame of three-dimensional volume (Figure 4b).

2.4. Rolling

Fabric or any malleable sheet is rolled over a tube bar by fixing one end of the sheet to the same bar and the other end to another tube bar. Bars are assembled together in a line at the open edges of a card. When one bar is pulled, the sheet starts to unroll, expanding the space (Figure 5a).When the rolling system is applied to a card, opened 90o vertically, the end of the rolled sheet is fixed with a bar attached to one end of the card and the other end of the sheet is fixed with another bar attached to the other end of the card. When the card is opened, the sheet starts to unroll and thus makes a three-dimensional volume (Figure 5b).

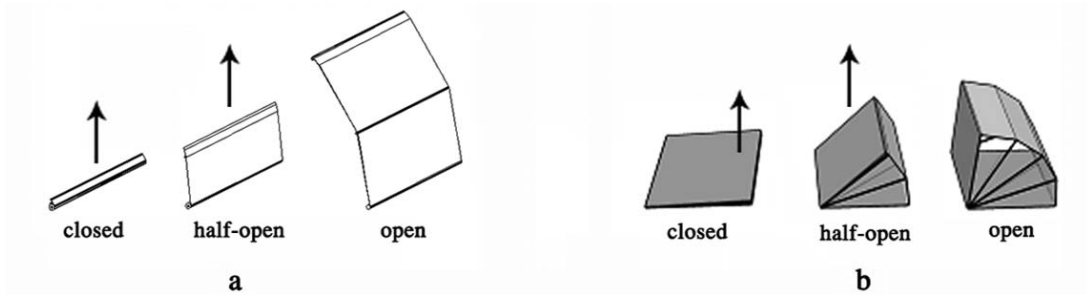


Fig 5. a - Rolling system, b - Pop-up of a card produced using the rolling system

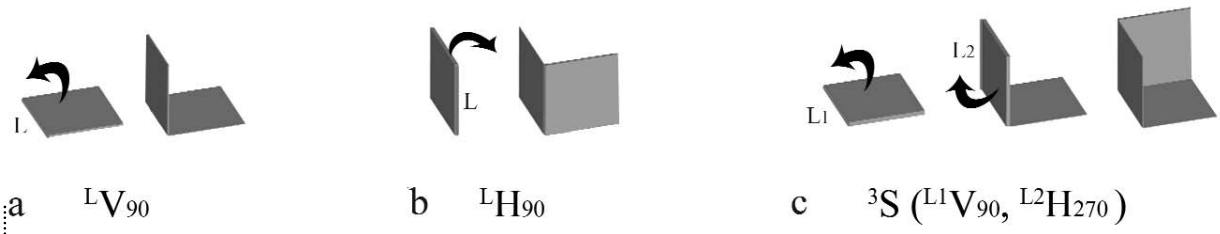


Fig 6. Various possibilities to open the card; a - Vertical opening, b - Horizontal opening, c - Combined opening.

3. GEOMETRIC CHARACTERISTICS OF OPENING THE CARDS

There are various ways to open a card, thus leading to the creation of numerous geometric forms through the adoption of one of the above discussed pop-up techniques. The opening of a card can be horizontal, vertical, or a combination of the two. Numerous flexible designs can be achieved by using compositions of different openings. To obtain a desired shape, geometrical compositions are considered before folding the cards. Furthermore, a variety of distinctive forms can also be produced on the basis of the angle of the opening.

In order to compose the desired shape and to widen the possibilities of creating various forms, a formal language of opening the card has been developed here. This language serves to direct the opening of the card by following a defined rule or formula. The formula defines the number of openings, and types and angles of openings as well. First, the initial composition is folded in a card based on a definite formula. The card is then opened by following the formula to produce the imagined outcome.

In the language of opening the card, vertical and horizontal openings are denoted by LVR and LHR, respectively, where L indicates the line of folding or crease and R defines the angle of rotation or angle of opening. The combination of two or more than two openings is denoted by NS(V,H) or NS(V) or NS(H) , where the combinations are vertical and horizontal openings, or a combination of consecutive vertical openings or consecutive horizontal openings, respectively (Figure 6). The notation N represents the number of total openings.

Consecutive N numbers of vertical openings, i.e., NS(V) , can be briefly represented by NS[(L1, L2, L3,….,Ln)V(R1, R2,R3,…..,Rn)] whereas NS[(L1, L2, L3,….,Ln)H(R1, R2,R3,…..,Rn)] represents consecutive N numbers of horizontal openings, i.e., NS(H). In the formulas of combined openings, R1, R2, R3,……Rn are the corresponding opening angles at creases L1, L2, L3, ….., Ln, respectively. Some combined openings on the basis of these formulas are shown in Figure 7.

By applying the formal language for opening the cards and on the basis of the formulas derived from this language, a number of flexible two-dimensional geometric forms can be predetermined. Conversely, after selecting the desired geometric form first, the primary folded shape can also be determined by employing the same formula. Some two-dimensional flexible and expandable geometric forms produced from various combined openings are shown in Figure 8.

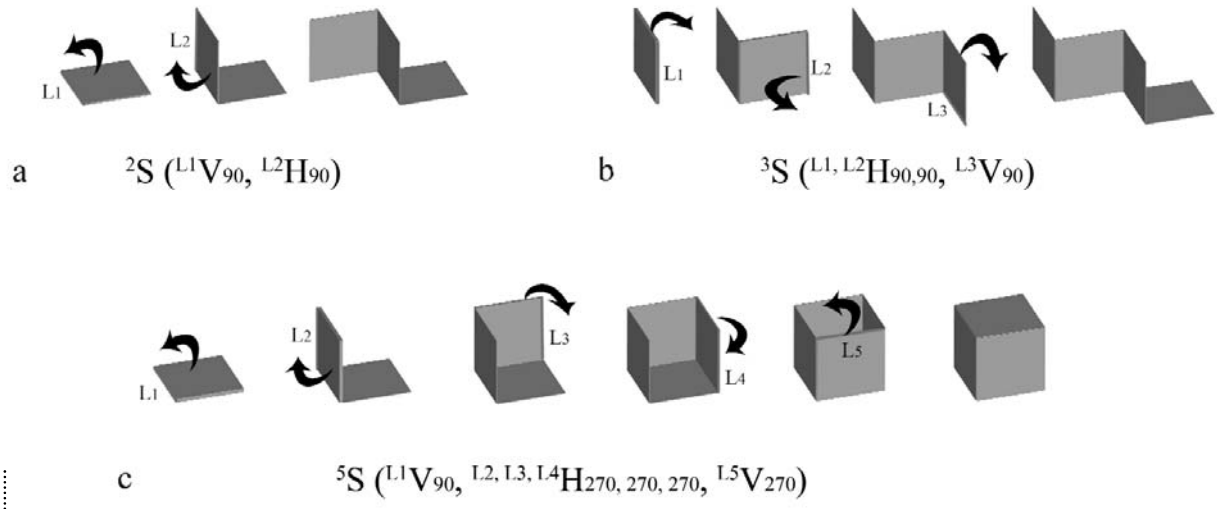


Fig 7. Various combined openings of cards and their formulas

Formula	Plan form
$^{3}S[^{L1}V_{90}.\ ^{L2}H_{90}.\ ^{L3}V_{90}]$	
$^{3}S[^{L1}V_{90}.\ ^{L2}H_{180}.\ ^{L3}V_{90}]$	
$^{5}S[^{(L1,L2)}V_{(90,90)}.\ ^{(L3,L4)}H_{(90,90)}.\ ^{L5}V_{90}]$	
$^{6}S[^{(L1,L2)}V_{(90,90)}.\ ^{(L3,L4)}H_{(90,90)}.\ ^{(L5,L6)}V_{(90,90)}]$	

Fig 8. Various flexible and expandable plan forms according to formulas for opening the cards

4. POP-UP TECHNIQUES APPLIED TO POST-DISASTER SHELTERS

By taking the above discussed forms as units and applying them to different types of combined openings, as shown in Figure 7, various plan forms can be readily produced (Figure 9). Principles of these geometric possibilities for making flexible and expandable shapes from single or pairs of closed cards have been applied to a post-disaster shelter system. The flexibility and expandability of the shelter designs are expected to play a major role in achieving social and cultural harmony. Accordingly, the formal language of opening the cards has the potentiality to build a local pseudo-society by reforming various shelter structures for usual (daily life) as well as emergency and recovery programs after the disaster.

Different types of flexible and expandable forms for the shelter can be produced by assembling the above units according to the new formal language of opening the cards, as discussed earlier (Figure 10). For a particular disaster affected area, a suitable flexible form can be selected for the shelter on the basis of post-disaster recovery programs as well as the local environment and culture, and can be thereupon erected within a few minutes. Because only one or two "pulls" will pop up various sizes of needed shelters from the folded units, infrastructures for a pseudo-society can be established within a few hours or days.

Different types of flexible and expandable forms for the shelter can be produced by assembling the above units according to the new formal language

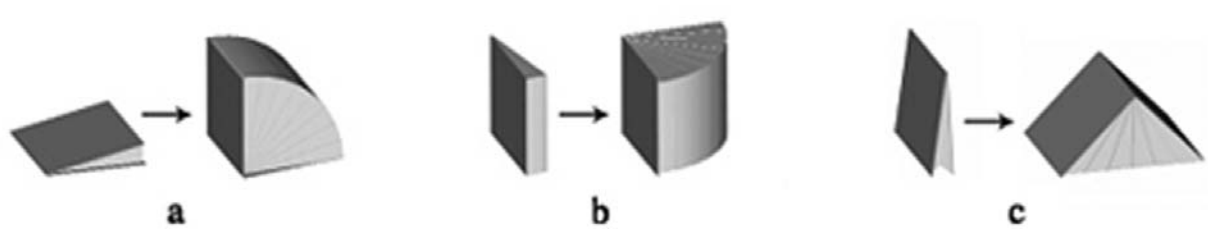


Fig 9. Structure produced from a - vertical opening, b - horizontal opening and c - inverse opening.

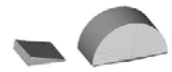
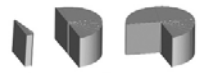
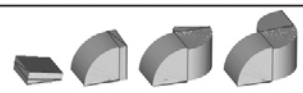
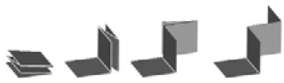
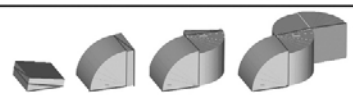
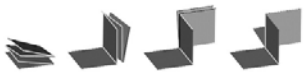
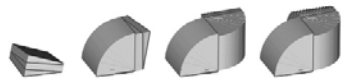
Formula	Opening	Structure
$^{L1}V_{280}$		
$^{2}S\ (^{L1}H_{180}, ^{L2}H_{90})$		
$^{2}S\ (^{L1}V_{90}, ^{L2}H_{90})$		
$^{3}S\ (^{L1}V_{90}, ^{L2}H_{90}, ^{L3}H_{90})$		
$^{3}S\ (^{L1}V_{90}, ^{L2}H_{90}, ^{L3}H_{180})$		
$^{3}S\ (^{L1}V_{90}, ^{L2}H_{90}, ^{L3}V_{90})$		

Fig 10. Opening possibilities of cards and their respective structures by using a pop-up technique

of opening the cards, as discussed earlier (Figure 10). For a particular disaster affected area, a suitable flexible form can be selected for the shelter on the basis of post-disaster recovery programs as well as the local environment and culture, and can be thereupon erected within a few minutes. Because only one or two "pulls" will pop up various sizes of needed shelters from the folded units, infrastructures for a pseudo-society can be established within a few hours or days.

In addition to the above styles of opening for creating various flexible and expandable designs, there are other possibilities of openings that can also produce numerous shapes and a variety of flexible designs using the same pop-up techniques. Among others, a lateral opening is shown in Figure 11, where a sliding system pop-up technique has been adopted. The lateral opening system allows

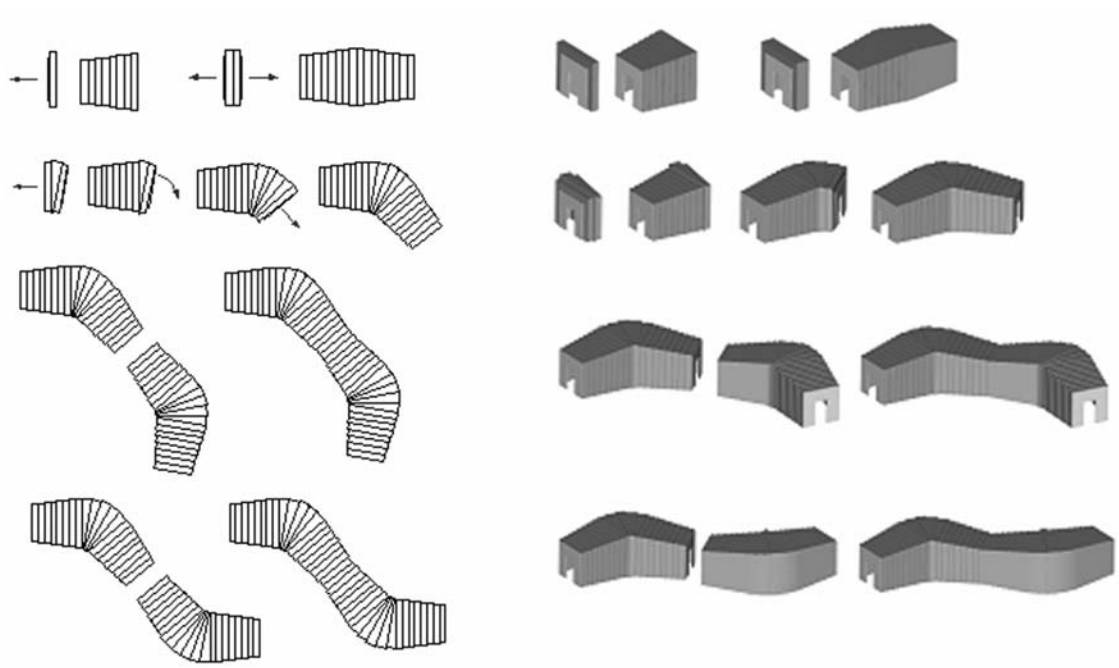


Fig 11. Flexibility and expandability of spaces produced from lateral openings by using a sliding pop-up technique (Left. Top view; Right: Perspective view)

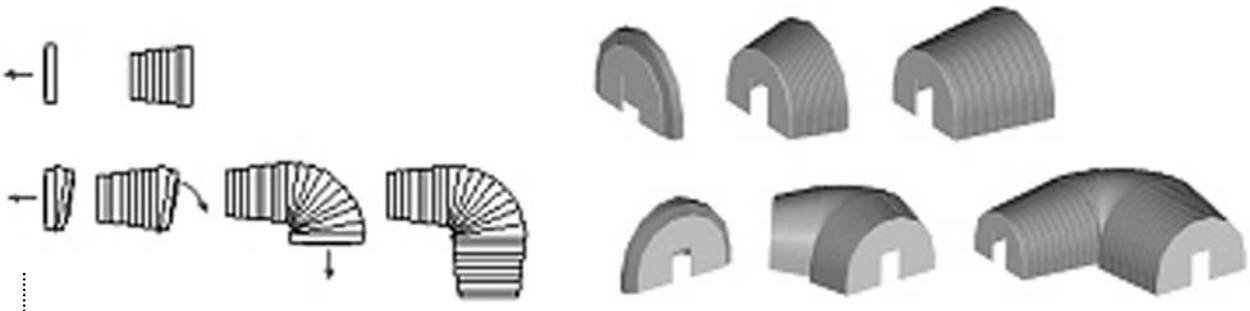


Fig 12. Lateral openings for expandable spaces by using different panel (Left. Plan view; Right: Perspective view)

the creation of various long and expansive structures. In this system, rectangular panels are assembled one by one according to decreasing size, thus making a folded shelter unit. When one end of the unit is pulled, a cubical shelter structure is created by sliding the rectangular panels. The length of this type of shelter can be elongated by increasing the number of panels in a unit. To add flexibility, i.e., to change the direction of a lateral expanding unit, a horizontal opening system can be added according to the desired product (Figure 11).

Application of the same lateral pulling system for different shaped panels will also produce a different kind of shelter form. By adopting suitable shaped panels, we can create shelter forms that reflect the local cultural identity. For example, if an area or society that has been hit by tsunami is architecturally characterized by arched roofs on houses, then as a post-tsunami deployable shelter we can adopt the system shown in Figure 12 to restore this local identity. In short, the proposed system partly focuses on the formal aspect of the shelter structure along with its spatial elasticity, resonating with the indigenous identity of the affected locale.

Various shapes and sizes of shelter units will be made through the shelter manufacturing industry using light-weight, local, durable, and weatherproof materials. The target group of the proposed solution is basically the most vulnerable people: those who have lost their homes in a disaster or conflict, particularly the most heavily affected community. This includes the poor, disabled, elderly, and single parent or child headed households. In addition, national or regional government, NGOs, and the local community are also included in the target groups who serve and require institutions (social, cultural, educational, and medical infrastructures). However, at different places, some manufacturing cells can be set up where the shelter units, especially roof and wall panels (including door and window panels), are to be manufactured using locally available, sustainable materials.

By employing the above pop-up system, the units can be designed and produced in such a way that shelter structures can harmonize with the local buildings of the region and fit into the area's social and cultural features. For example, shelter units or panels can be made with bamboo straw and bamboo branches in a region where bamboo is amply available. A shelter structure made with bamboo will have greater affinity with the people of that region. In this way, the system allows for local production of the shelter structure using the aforementioned pop-up technology.

Nevertheless, the utilization of cardboard as the main building material for the shelter is convenient, since cardboard is a common building material in almost all regions around the world and can be produced using locally available wood, straw, paper, or recycled cardboard. Although shelter units produced from cardboard are preferable in terms of technical implementation and weather protection and durability, locally produced building materials are more preferable from the perspective of maintaining cultural identity. However, cardboard has been chosen for demonstrating the implementation of the proposed technical solution and prototypical shelter.

5. PROTOTYPE SHELTER: DESIGN AND CONSTRUCTION

In this research, a sliding system has been chosen to design a prototype of a post-disaster emergency deployable shelter as part of an experimental

demonstration. In the shelter prototype, a small number of light-weight shelter-components are considered for simplicity in assembling the components and to make the shelter units rapidly on the site. According to numerous case studies of post-disaster recovery programs, it has been observed that after recovery it becomes impractical to return the shelter structure to the donor for use in a future disaster situation on another site. Instead, victims tend to reuse the shelter materials for the construction of a permanent settlement (Babister and Kelman, 2002). It is thus preferable that such materials can be reused during the transitional or permanent settlement, or can be recycled. For this reason, corrugated cardboard sandwiched by plain cardboard surfaces has been chosen as the main building material for the shelter for its excellent environmental sustainability. It is cheap, strong, widely available, durable, and recyclable. It is as rigid and can withstand heavy wind-load from sagging, and flexible enough to be reformed into any shape (Damatty, et al., 2000). In addition, it can be sawed, nailed, sealed, laminated, and coated with fire retardant or waterproof surface treatment (Cripps, 2004). For the prototype, proper treatment at joints and edges is critical to protect the shelter from the weather and to provide adequate strength. Cardboard is painted by intumescent varnish, and polyurethane is employed over the varnish; the varnish makes the board fireproof and polyurethane makes it waterproof and damp-proof. Since cardboard can be manufactured cheaply via small and simple machinery, there is also the potential to produce the materials on-site and thereby reduce transportation costs (Ban, 1998).

5.1. Components and their assembly

The components mainly consist of two supporting bars of height 330cm and 280cm, five 3cm thick inverted L-shaped cardboard panels with triangular tops, sloping 10o downwards (named 'roof-wall panel 1'), and five 3cm thick inverted L-shaped cardboard panels with triangular tops, sloping 10o upwards (named 'roof-wall panel 2'). These L-shaped elements are used for making the roof and walls, where the triangular top part of the panel defines the roof, and the vertical rectangular part of the panel defines the wall. Slopes are provided for drainage of rainwater. The height and width of five 'roof-wall panel 1' segments decrementally decrease by 3cm such that the panels can be assembled one below another by fixing their triangular ends at the same center. The same design has also been executed for 'roof-wall panel 2'. The slopes are taken oppositely for two types of L-shaped panels in order to continue to make a flexible and expandable space by maintaining a common slope on the roof of the final shelter as the units are joined. Apart from these components, there are also four 3cm thick trapezoidal wall modules having two different sizes according to the sizes of the end L-shaped panels of a unit (Figure 13).

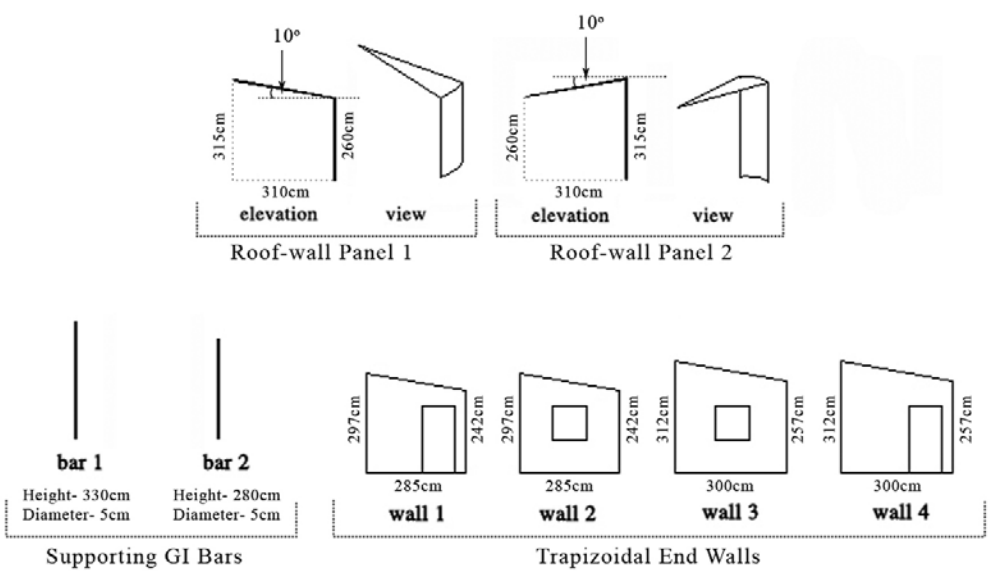


Fig 13. Principal components of the prototype post-disaster deployable shelter

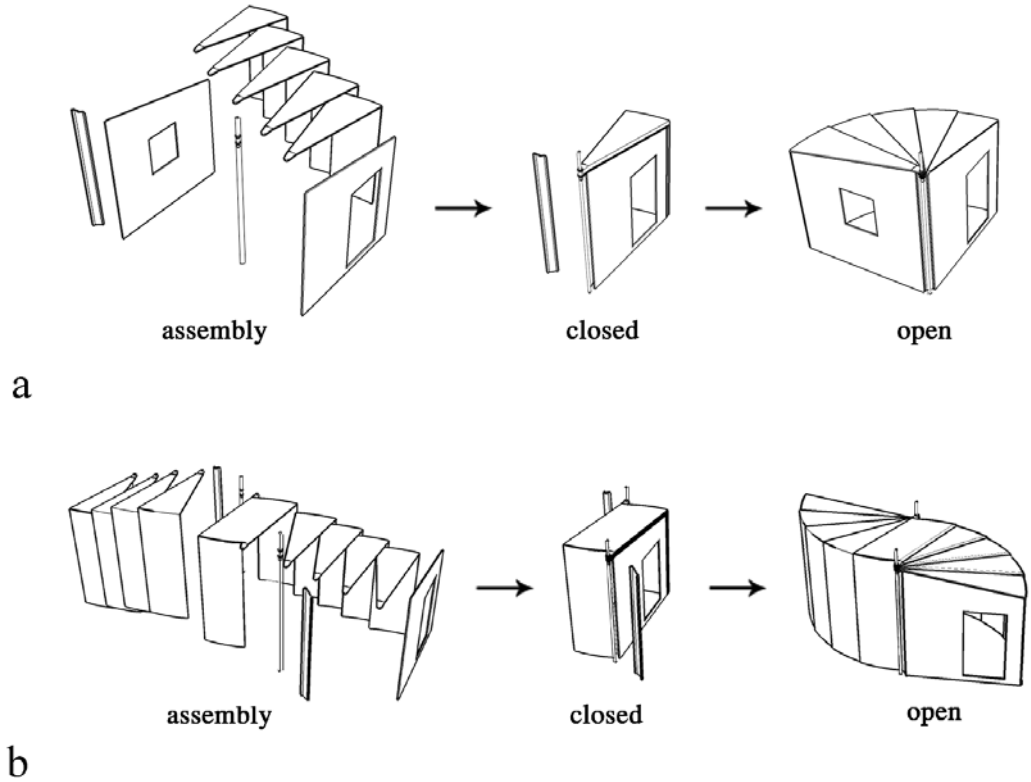


Fig 14. a - Assembly of one unit, b - Assembly of two units.

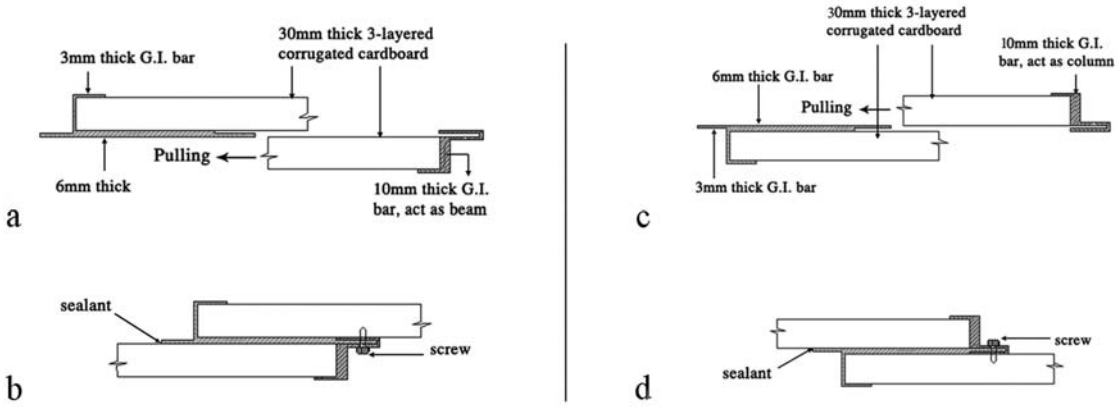


Fig 15. Left - Roof Section-Details; a - Before pulling, b - After pulling; Right - Wall Section-Details; c - Before Pulling, d - After pulling.

All L-shaped elements for the single unit are assembled as shown in Figure 14. They can revolve by sliding them one by one, where the supporting bar is located at the center by pulling one of the first or the last elements. The wall components are then attached to the end L-shaped elements according to the desired structure size (Figure 14a). In this fashion, the horizontal opening of a closed unit creates a shelter space. By increasing the number of L-shaped elements in a unit, different shapes of shelters can be achieved. Thus, a variety of possible shapes can be produced according to the rotational angle of the horizontal opening. Figure 14b shows the assembly of two units.

5.2. Protection

A 1cm galvanized iron (GI) bar fixed with one edge of each panel acts as a beam for the roof part and

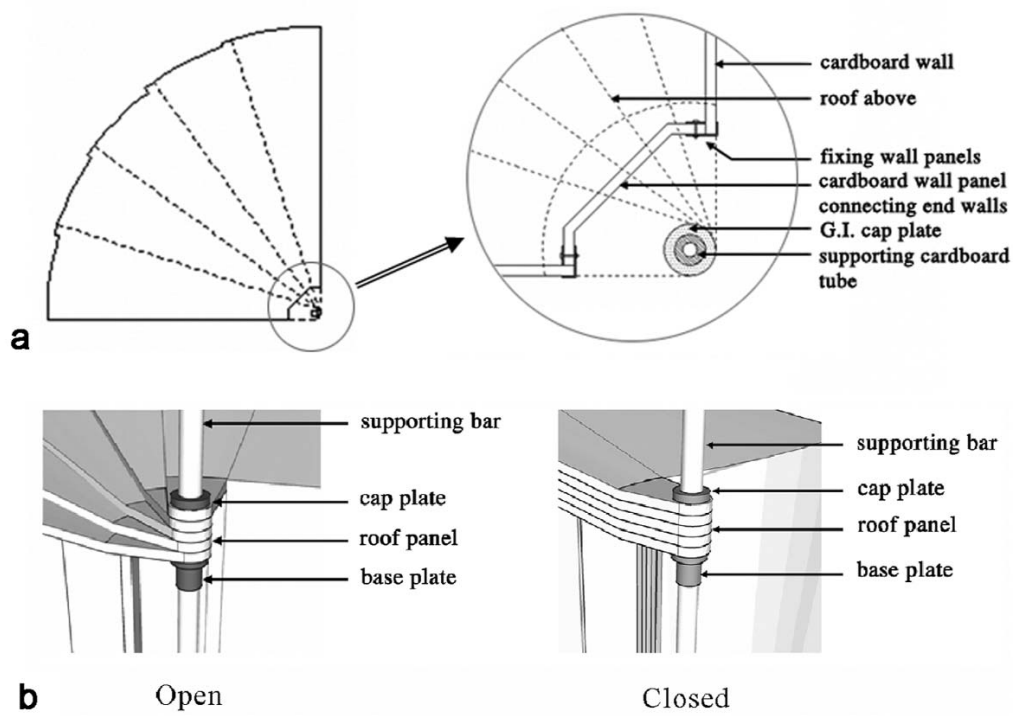


Fig 16. Details of the concentric assembly of roof-wall panels at supporting bar; Up- Plans, Below- Views

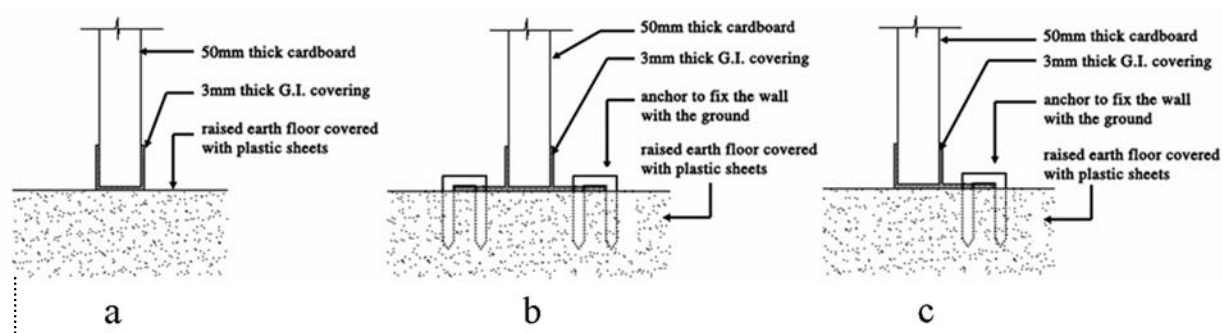


Fig 17. Sections: a - bottom of door panel, b - bottom of end wall panel, c - bottom of roof-wall panel.

as a column for the wall part. When the unit is opened by pulling, GI brackets of the lower panel are anchored with the projecting 3mm thick GI bar of the upper panel, both at the roof and wall (Figure 15 and 16). After the panels are anchored and fixed together, they are further tightened to each other by bolting at the anchored part. For further protection from rain and weather, the board-bar joints and bolting parts are sealed by a sealant.

After opening a unit by pulling, a small gap is created at the supporting bar by the trapezoidal shaped end walls, which are not full length for ease of panel rotations (Figure 16a). This gap is filled by an extra cardboard wall panel reaching to the underside of the roof from the ground and fixed by bolting it with the end walls (Figure 16b). Finally, the gap is sealed with sealants to make the structure weatherproof.

Before erecting the shelter, a raised plane platform is made by gathering soil on the site. The soil is bordered by bricks or wood or other hard panels collected from structures destroyed by the natural disaster. The earth is then compacted to make the floor plane and subsequently covered by a plastic PVC sheet to provide floor durability. The plastic sheet protects the cardboard wall panels from dampness caused by the earth or surrounding ground during and after rainfall. Once the platform is made, the supporting bar is affixed deeply into the platform so that the roof-wall panels can be moved easily to erect the shelter structure. After erecting and adjusting the structure on the platform,

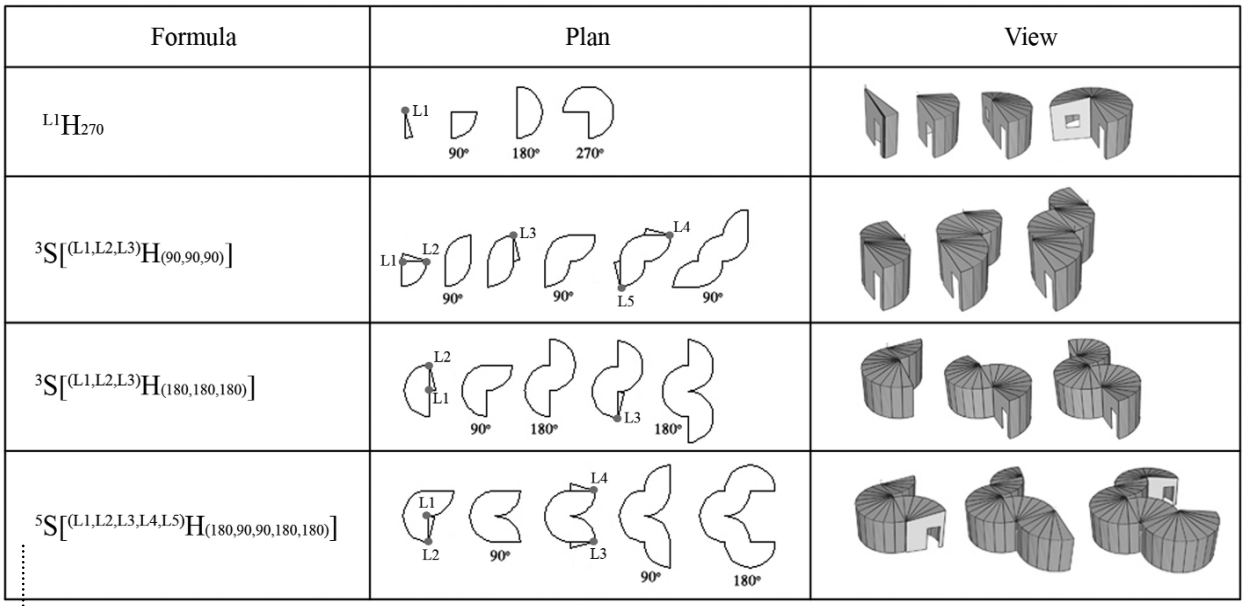


Fig 18. Various possibilities of flexible shelters by grouping units

the walls are anchored by channel-shaped anchors on the floor so that the structure is secured tightly to the ground. The cardboard panels are weatherproofed by coating only the exterior surfaces of the panels. Otherwise, leakage through the cardboard would allow water to enter and thereby weaken the strength of the cardboard and cause the panel to sag. For this reason, when anchoring the walls to the ground, the bottom edges of the panels are fixed by a 3mm GI bar (Figure 17) to avoid damage or leakage caused by nailing the anchor. In addition, the GI bar serves as a hard base for the wall and protects the cross-section of the cardboard panel from dampness in the ground.

5.3. Transportation

The shelter units assembled with cardboard components will be manufactured in factory and stocked in the factory store room, local shelter storeroom, or shipped to different shelter target groups, as noted earlier. The units are designed to be not longer than 3 meters so that a standard size truck can deliver roughly fifty shelter units. When a disaster or conflict occurs, the readymade deployable shelter units will be supplied by truck to the affected area for the most critical relief programs, such as the construction of dwellings, trauma centers, sanitation and food distribution facilities, etc. Soon after, a number of shelters will be erected for other social programs, such as schools, markets, religious facilities, etc. as well as for recovery programs. In cases where transportation by land transporters is not feasible, a medium to large size boat or a helicopter will bring a number of shelter units to the disaster hit area. Once the transporter brings the units to the distributor at the affected area, two persons can easily carry one shelter unit to the construction site.

5.4. Grouping of units

By using the formal language for opening the cards, the unfolded shelter units can be grouped together in such a way that when the units are opened, larger flexible and expandable designs with a variety of geometric configurations can be realized (Figure 18). In the prototype fabricated here, the formula for combined consecutive horizontal openings, i.e., NS[(L1,L2,….,Ln) H(R1,R2,…,Rn)] is employed.

The diverse resultant plan layouts followed by the formulas for opening the cards can provide a wide variety of designs. Any layout that is suitable for a particular program can be selected. In addition, a preferred design can be flexibly and conveniently achieved by grouping units. Flexibility of inner spaces can also be attained by providing or eliminating inner wall panels during the grouping of units. Furthermore, a variety of shelter designs can be produced by controlling the number of L-shaped elements in a unit. The number of L-shaped elements defines the angle of the horizontal opening and different opening angles create different forms

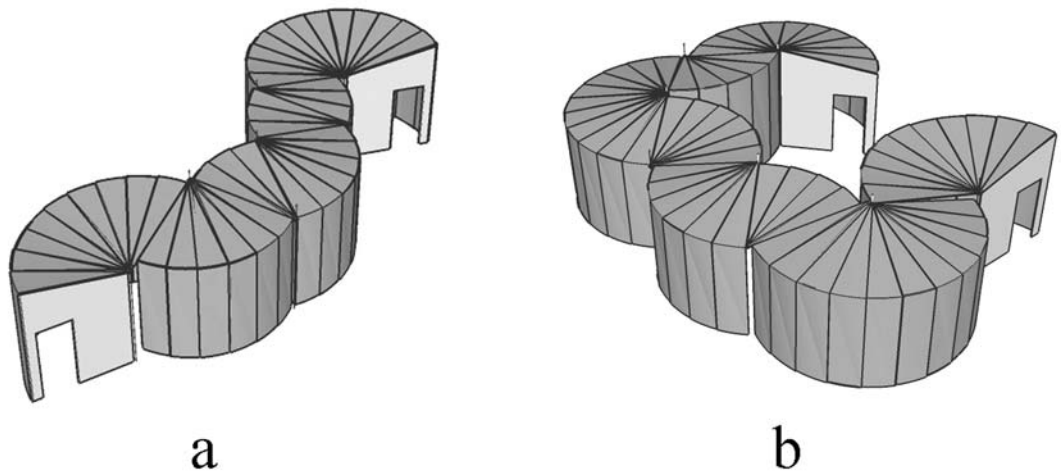


Fig 19. Various possibilities of flexible shelters by grouping units

of shelter structures, as shown in Figure 18. As a result, the sliding pop-up technique adopted to make deployable shelter units has considerable potential to rapidly make the infrastructure of a pseudo-society for different social programs through the opening and grouping of shelter units. Some other flexible shaped shelter structures are shown in Figure 19. These are produced by using the formula for opening the cards where the folding or opening line L and the opening angle R are continuously changed.

6. CONCLUSION

Users and inhabitants are the best architects and critics of their own building environment. Since people first began living in permanent dwellings, they have been constantly changing, renovating, remodeling, and otherwise updating their living spaces (Brand, 1994). Through changing lifestyles and needs inhabitants render their environment suitable to them and continue to adapt their surroundings accordingly. Disasters destroy not only lives and property but also these self-made environments, be it a single house or an entire community. Conventional temporary emergency shelters are generally of one or two types having a rigid space in which the victims are forced to reside, regardless of their desired living environment. During the emergency period, temporary shelters are indispensable as homes rather than mere residences. Therefore, in order to reestablish socio-cultural continuity and livelihoods, flexibility in shelter design is necessary so that users can mold the space as needed or desired.

In summing up, this study proposes the design and construction process of a post-disaster shelter. The strengths of the design include systematic use of the pop-up technique of origamic architecture, geometric elasticity, and simplicity of construction by any unskilled person, thus providing extraordinary variety of flexible spatial designs needed for post-disaster shelters. In addition, local committee and local volunteers will be trained to distribute and assist users to erect the shelter. At this time, various local skills and knowledge will be assimilated.

The scope of this solution is limited to setting up the basic infrastructure, i.e., the fundamental base for the process of sheltering only, but does not single-handedly solve all the problems identified at the beginning of this paper. The proposed solution contributes to the required solutions that directly or indirectly rely on each other.

Whereas this paper attempts to solve these problems from a technological point of view, a technical solution is not sufficient to fully bring livelihood and socio-cultural continuity to the affected community from economical, educational, political, and physical perspectives. Accordingly, the implementation of community-based approaches to disaster mitigation is imperative for bringing the successful recovery and sustainable development in the community (Maskrey, 1989).

Awareness of the need for precaution and safety in any kind of disaster or conflict is of foremost importance. As Spence (2004) pointed out: "the success of any government action depends equally

on the development in a society of a 'safety culture' in which citizens both understand the risks they face and are prepared to participate in the management of them." Therefore, the strong involvement of people from technological, social, and political spheres, as well as members of the civil community, is needed to minimize loss of lives, protect survivors from hazard and vulnerability, and to reestablish social and cultural continuity of the affected area in the event of small scale to large scale disasters or conflicts (Lorch, 2005).

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REFERENCES

BABISTER E, KELMAN I, 2002 *The Emergency Shelter Process with Application to Case Studies in Macedonia and Afghanistan*, Ph.D. Thesis, University of Cambridge, London.

BAN S, 1998 *Paper Tube Architecture from Rwanda to Kobe*, Chikuma Shobo Publishing Co., Ltd., Japan.

BRAND S, 1994 *How Buildings Learn*, New York, Penguin Books.

CHATANI M, 1984 *Pop-up Origamic Architecture*, Ondorisha Publishers Ltd, Japan.

CRED, undated, 'CRED International Database on Disasters: EM-DAT", Centre for Research on the Epidemiology of Disasters, Catholic University of Louvain, Belgium.

CRIPPS A, 2004 "Cardboard as a construction material: a case study," *Building Research & Information*, 32/3: 207-219.

DAMATTY A.A, et al., 2000 "Finite element modeling and analysis of a cardboard shelter, Thin-Walled Structures," *Elsevier Science*, 38/2: 145-165.

DAVIS I, 1978 Shelter after Disaster, Oxford Polytechnic Press, London.

EM-DAT (GUHA S, HARGITT D, HOYOIS P.) 2004 *Thirty years of natural disasters 1974-2003: The numbers,* Presses Universitaires de Louvain: Louvain-la Neuve. [ID n202], pp 57.

FOSTER S., FOWLER J., 2003, Report on the Transitional Settlement Sector, www.shelterproject.org

SAGLAMER G., et al., 2006 "Reconstruction of Satisfactory and Culturally Appropriate Neighborhoods in Turkey," *Open House International*, 31/1.

HABRAKEN N.J, 1972 *Supports; An Alternative to Mass Housing*, Architectural Press, London (Dutch Version, 1961).

I.S.D.R., www.unisdr.org/disaster-statistics/pdf/isdr-disaster-statistics-impact.pdf (March, 2007).

KENDALL S, TEICHER J, 1999 *Residential Open Building*, Spon, London.

LORCH R, 2005 "What lessons must be learned from the tsunami?" *Building Research & Information*, 33/3: 209-211.

MASKREY A, 1989 *Disaster Mitigation: A Community-Based Approach,* OXFAM, Oxford.

MIURA K. et al., 1980 *A Novel Design of Folded Map*. Congress of the International Cartographical Association, Tokyo.

RAUTELLA P, 2006 "Redefining Disaster: Need for Managing Accidents as Disasters," *Disaster Prevention and Management*, 15/5: 799-809.

SCHILDERMAN T, 2004 "Adapting traditional shelter for disaster mitigation and reconstruction: experience with community-based approaches," *Building Research & Information*, 32/5: 414-426.

SPENCE R, 2004 "Risk and regulation: can improved government action reduce the impacts of natural disasters?" *Building Research & Information*, 32/5: 391–402.

UNEP. 2005 *MALDIVES: Post Tsunami Environmental Assessment*. United Nations Environment Program. Nairobi. Kenya.

WISNER B, WALKER, P. 2006 "Getting Tsunami Recovery and Early Warning Right," *Open House International*, 31/1.

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