Integrating Shelter Design and Disaster Education in Architectural Curriculum

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Abstract

Education of the public is greatly important in order to change the approach to disasters from reactive to preventative. However, this does not eliminate the need to constantly upgrade and improve the designs of disaster-relief structures. Disaster-relief shelters are crucial to the post-disaster rescue and recovery as millions of people are affected by various catastrophes which have only increased over the years. Architects and engineers can contribute greatly to the education of society about shelter design strategies for various disasters.

This paper focuses on earthquakes, floods, megafires and hurricanes, and the potential design response to counter each of them. Design solutions based on modularity and deployability are reasonable considering the benefits of compactness, ease of storage, transportation, and reuse. A series of prototype designs are presented to illustrate their design features and efficiency.

The paper also discusses how an architectural curriculum may be enhanced by infusing service-learning and real-world opportunities by including studios and seminars on disaster-relief shelter design and education. They may be offered to students in architecture, urban planning, social work, education and allied disciplines. The outcome of these courses may be developed as educational aids for use in schools, local communities and for the general public in order to help with the understanding of local conditions, potential disasters, design strategies and prototype shelter designs.

Key Words: disaster-relief, shelter, modularity, deployability, architectural education, community, service-learning

1. Introduction

Time and again, humans have realized that they have little control over natural disasters such as earthquakes, tsunamis, hurricanes, floods, tornadoes, and wildfires, which are the most dominant of all. The recent hurricanes Harvey, Irma and Maria have revealed our vulnerability to respond adequately to disasters of severe magnitude. Natural disasters have started to occur at an increasing rate and killing thousands of people each year, affecting both developed and developing countries alike. Survivors are often isolated, difficult to reach and stranded in dangerous and volatile environments. Statistics reveal inadequate preparedness and the difficulties experienced in coping with problems frequently encountered in the intrinsically chaotic disaster-relief operations. A life-support system is the real need, not just an emergency shelter to be deployed rapidly after natural disasters strike.

Disaster education, as such, becomes crucial to propel the creation of resilient communities. It is offered in various countries based on local socio-economic and cultural contexts. Shaw et al. [10] provided a comprehensive and easy-to-understand overview of disaster education based on field experiences. Through a series of case-studies including those from Japan and Nepal, they discussed the ongoing efforts in promoting disaster education.

This paper examines the influence of different natural disasters on shelter design. Emergency structures are extremely important in both post-disaster relief and recovery. However, the design of emergency structures and shelters are often overlooked in mainstream architectural education. The paper argues that architectural and structural design pedagogy may be greatly enhanced with the inclusion of studios and seminars on disaster-relief shelters. The case for formal education on the subject becomes pivotal especially in rethinking the design of disaster-relief shelters as integrated shelters, i.e., structures integrated with essential needs such as furniture and toilets. The efforts for increasing public awareness of disasters and their risk reduction can be extended through knowledge of shelter design for various disaster-types. The characteristics of specific disasters are discussed and potential solutions are provided for shelter design using deployable modular structures.

2. Characteristics of disasters

According to emergency health training program for Africa [17], a disaster can be divided into three phases: (1) the pre-disaster phase, (2) the disaster/impact phase, and (3) the post-disaster and reconstruction phase. However, each disaster may cause destruction of different intensity. Moreover, disasters, from their occurrence, development to extinction, vary from each other in their characteristics. Table 1 provides a summary of the disaster characteristics and effects.

Table 1 Characteristics of disasters

Disasters	Earthquakes	Floods	Megafire	Hurricanes
Disaster category	Geophysical	Hydrological	Climatological	Meteorological
Effects	Damage to structure due to intense ground motions and aftershocks	Ruined structure and inundation by flood	Charring, spalling, and melting due to high temperatures	Flying roofs, broken windows
	Fire caused by collapse	Rainstorm, thunder and lightning accompanying floods	Smog and smoke	Rainfall, thunder and lightning accompanying storms
The pre-disaster phase	Very short and unpredictable	Usually predictable	Prevention and warning system can extend the escape time	Usually predictable
Disaster/impact phase	Short but aftershocks may continue for years	Land may be covered with water from days to months	Could last long, spread far and wide	Relatively short
Post-disaster and reconstruction phase	Long term reconstruction and recovery	Long term depends on the intensity of flooding	Long term reconstruction and recovery	Long term reconstruction and recovery

3. Shelter types and their design

Disaster-relief shelters are a critical need considering the fact that thirty million people on average are displaced each year by natural disasters [4]. Depending on the function and service time, shelters may be categorized as: emergency shelters, temporary shelters, temporary house, and permanent house [9, 16]. In a more detailed classification, shelters are classified into seven types: emergency shelter, temporary shelter, temporary housing, transitional housing, transitional shelter, progressive shelter, core/one-room shelter, and permanent housing by the International Federation of the Red Cross and Red Crescent Societies [8]. In the subject of shelter design, various topics have been studied such as materials [14], structural systems [1, 7], geographic locations [6, 11], climatic issues [13], and economic issues [2].

As disaster management strategies are evolving, improved designs for emergency shelters and facilities should be considered as a necessary part of the planning efforts. "Build back better" has been the lesson of the past. "Design better" is the much needed first step. The design approach and designs ─ both have to be transformative. Design of disaster relief shelters must go beyond just sheltering the affected against the elements of nature. They should be designed to promote emotional well-being of survivors and help with their recovery from what may have been a cosmic event in their lives. Modularity and deployability are two fundamentally desirable characteristics that are discussed herein.

Modularity and deployability

Modularity refers to use of prefabricated units that may be repeated to form expanded structures and clusters. Because of repetition of units, manufacturing, stowing and transportation can be strategically planned to create an economical system suitable for quick assembly [3]. The advantages of modular structures include: (1) shorter construction time, (2) less labor, (3) safer working conditions, (4) better quality, (5) less material waste, and (6) less environmental impact. All of these merits are crucial for post-disaster relief. In the disaster/impact phase, shorter time and less labor signify more refugee can be saved; in the post-disaster and reconstruction phase, better quality and less environmental impact will promise an effective recovery.

A solution based on deployability of structure is an effective way to overcome the disadvantages of both kit-of-parts solution and ready-made units. Deployable structures are those that can be folded or packaged into small volumes and then be deployed or expanded to a larger size for use. Thus, they allow for easy storage, transportation, and reuse. They are best realized as prefabricated systems that have all the advantages that modular systems possess.

In the disaster relief or humanitarian aid, logistics management and supply chain management are the most challenging assignments. They are also the most expensive and make up 80% of the cost in disaster relief [15]. Figure 1 helps to determine the most suitable way for relief transportation depending on the available means. The factors to be considered are:

1. Disaster type (natural disaster, man-made disaster)
2. Severity of the disaster (degree of destruction of infrastructure)
3. Climate in the disaster area (heavy rains, thunder and lighting, etc.)
4. Geography of the disaster area (plains, mountains, coastal, urban)
5. Type of relief goods (their weight, size, emergency or not)
6. Number of refugees (for amount of goods needed)

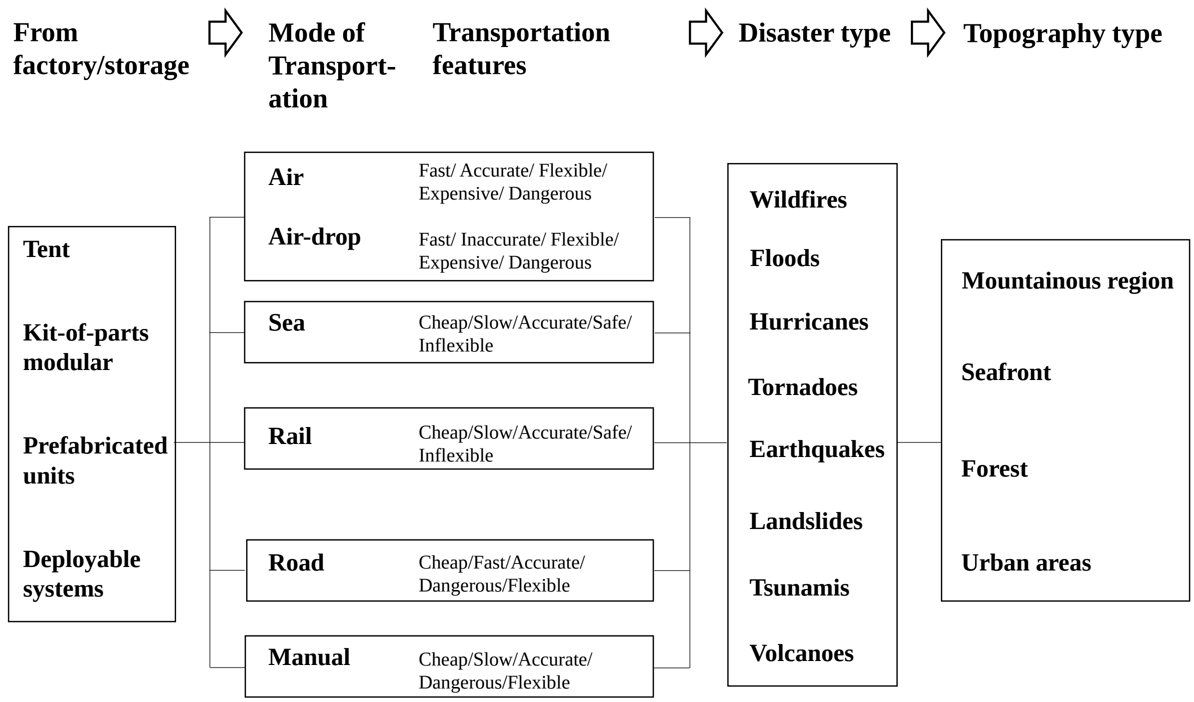


Fig. 1. Transportation methods in post-disaster logistics management.

The aforementioned factors should be considered comprehensively to determine the optimal means of transportation, i.e., we must find a balance between the objectives: (1) the safety of transportation, (2) the accuracy of delivery, (3) the cost of management, and (4) the time commitment of relief. Emergency shelters and their management are crucial for post-disaster relief because they provide the essential survival and recovery conditions. Therefore, modularity and deployability are apt strategies for shelter design.

4. Design guidelines

Since shelters must be designed to mitigate the risk of death or injury, studying the characteristics of each disaster and designing shelters specific to a disaster type become essential. The safety and functionality of a shelter can be improved in two ways: (1) by choosing a safe location far away from the disaster center and planning an ideal layout for the shelters, (2) by optimizing the designs based on the unique characteristics of different disasters. The fundamental steps include geometric design, material and structural system selection (Table 2).

Three distinct prototypes are presented here. Each prototype has its own merits. Design Prototype-1 caters to fires and earthquakes, Design Prototypes-2 and 3 for floods, storms and landslides. The examples may be treated as fundamental considerations to develop more sophisticated designs considering other factors.

Table 2 Recommendations for shelter planning and design due to different disasters

Disaster	Effects	Location and layout [8]	Shelter design [8]
Earthquakes	Aftershocks, displacement of ground, collapse	1. Avoid fault lines, river beds, and coastal areas. 2. Keep enough space between shelters and between clusters.	1. Use lightweight materials. 2. Design rigid structural connections or use eccentric bracings.
Floods	Lateral loads, inundation, moisture	1. Avoid flood plains, high water table areas. 2. Plan simple drainage systems.	1. Use water-proof materials. 2. Raise shelters above ground. 3. Design floating shelters.
Megafire	Fire, smog and smoke	1. Avoid downwind area. 2. Plan fire breaks between fire and shelters.	1. Use fire resistant materials. 2. Plan escape ways. 3. Carefully design electric facilities (low voltage or battery) and kitchen (no gas).
Storm	Wind loads, rainfall, lightning	1. Avoid areas close to strong winds, tall constructions or trees. 2. Building orientation and layout should be carefully planned to help mitigate the effects of wind.	1. Use strong materials and structural systems. 2. Design foundation or anchor to ground. 3. Optimize building form to resist wind.

Design Prototype-1 (Fig. 2a)

Designated disaster: Earthquakes, volcanic eruption and megafire.
Materials: Lightweight and fire-proof materials with rigid connections.
Deployment: Walls are first deployed followed by the roof.
Features: (1) Lightweight materials and rigid connections can resist the shaking of earth.
(2) Fire-proof materials can resist fire.
(3) Good compactness for storage and transportation.

Design Prototype-2 (Fig. 2b)

Designated disaster: Floods, storm and landslides.
Materials: Water-proof materials with rigid connections.
Deployment: The walls fold to mobilize the roof that is attached to the walls.
Features: (1) Water-proof materials and rigid connections for water and lateral load resistance.
(2) Sloped roof to discharge rainwater.
(3) Compactness for storage and transportation
(4) Shelter can be raised on columns/piles to avoid contact with water.

Design Prototype-3 (Fig. 2c)

Designated disaster: Floods, storm and landslides.
Materials: Continuous water-proof materials with no gaps and rigid connections.
Deployment: Walls deploy by twisting motion.
Features: (1) Water-proof materials and rigid connections for water and lateral load resistance.
(2) No gaps during deployment, therefore the continuous water-proof material and insulation layers can work better.
(3) Good compactness for storage and transportation.

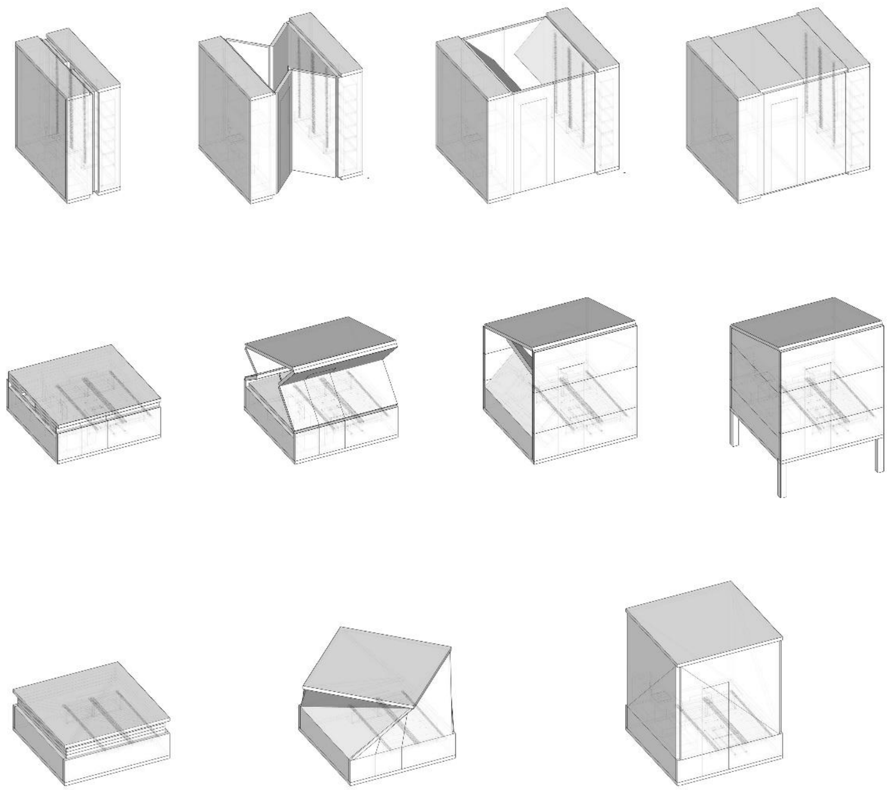


Fig. 2. Folding and deployment mechanism of design prototypes

5. Framework for the education on emergency shelters

Recent work by Kumar [5] discussed educational programs to help youngsters understand how to deal with natural disasters. Takagi [12] developed a smartphone application that illustrates rescue strategies during natural disasters. While NGOs plan an important role in educating communities, teachers can plan a crucial role in educating students about disasters.

Proposed Courses

Design for disasters and disaster-relief is conspicuous by its absence in architectural curricula. There may be a few exceptions to this. Regrettably, when design is disregarded, we make do with tents and rapid-assembly box-type structures. As such, there is a need to rethink shelter design and make it a formal part of architectural education. In the recent past, shelters have primarily been designed as part of open design competitions [22]. The goal of this model is to educate students on shelter design and engage them in service-learning. The proposed courses would be developed to provide introductory knowledge and fundamentals for undergraduate students based on given disaster scenarios and to provide specialized and in-depth knowledge based on specific case-studies of disasters to graduate-level students. Shelter design would be at the core.

(i) *Seminar*

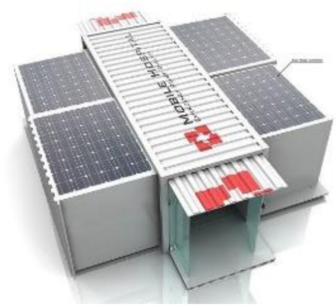
A teaching model based on the research is proposed as a seminar course (Table 3) and as an architectural design studio (Fig. 3). The objectives are: (1) human-centric design, (2) design of efficient modular and deployable systems, and (3) integration of essential needs in shelter design.

A seminar course as outlined in Table 3 may focus on learning the design process of rapid-assembly disaster-relief shelters. During the first six weeks, students would learn about extreme environment and disasters, infrastructure planning and transportation, and precedent designs (Table 4). In weeks seven through twelve, students will work on schematic designs considering as many variables – type of disaster, culture, climate, location, accessibility, local materials, and availability of human and physical resources, among others. Study of space-saving foldable furniture and integrating them with the structures would be simultaneously done. During weeks 13-15, students will optimize their designs using parametric and structural analyses programs. Table-top prototypes will be made for an intuitive understanding of motion of parts, expansion and packaging of the designed forms.

Table 3 Sample outline for a seminar course of disaster-relief shelter design

Week No.	Topic
1	Study of Disaster Environments and Extreme Environments
2	Disaster Analysis
3	Infrastructure Planning and Disaster Management
4	Transportation and Networks
5	Resources and Technology
6	Case Studies (see Table 4)
7 - 12	Disaster-relief Shelter Design A. Design Theory: Architecture and Human Settlements, Urbanism B. Program requirements C. Modular and rapid-assembly systems i. Systems integration ii. Optimal module sizes iii. Deployable system design (digital) D. Integrated Systems i. Architectural and other non-structural elements ii. Foldable space-saving furniture design iii. Integrated design strategies
13-15	Advanced Analysis and Design A. Deployment and reliability analyses (digital and physical models) B. Structural analysis and optimization (SAP2000) C. Design prototyping and testing

Table 4 A partial list of precedent studies for emergency shelters

Emergency shelter prototype	Description	Drawing/ Image
Project: Mobile Hospital **Designer:** Kukil Han [18]	Public clinics shelters to treat refugees. **Structure:** Foldable containers **Features:** About 40 m^2/4-8 persons for each unit	
Project: Self-deploying houses **Designer:** Ten Fold engineering [19]	Structures can unfold itself without the need for foundations, builders, or cranes. **Structure:** Deployable linkages and solid panels. **Features:** Deployment takes10 minutes using a hand-held battery-powered drill. The drill is put inside the building and the kinetic energy is transferred by the linkage to each structure element.	 
Project: Rapidly Deployable Shelter (RDS) **Designer:** Eureka! [20]	A rapidly deployable system. **Structure:** Truss-style frame system is stronger and more durable than standard "scissor" style frames and can withstand 300 lb. hanging load at any point on the frame. **Features:** Mission-ready in under 10 minutes. Nine sizes available to meet the needs of first responders.	 

Project: Shelter Pack **Designer:** Designnobis [21]	A flat pack, easy to transport, easy to assemble shelter of 12m^2 area. **Structures:** Kit-solution with rigid panels. **Shelter Features:** Each unit consists of four single beds, a bathroom, a fully equipped kitchen, a folding dining table and a storage area.	 

(ii) *Design Studio*

An architectural design studio would broaden the inquiry of meaning through values and ethics as they relate to time, place, and human needs. Factors such as type of disaster, culture, climate, location, accessibility, local materials, availability of human and physical resources, among others, should to be taken into account in the design of disaster-relief structures.

A studio project may be offered along the lines of the competition *Shelter 48*. The design challenge was captures in the following question – “How can architecture and design help protect, shelter and save lives when they strike?” The idea was to design a shelter for the immediate aftermath of a disaster [22]. Generally speaking, a studio may consider a larger time-frame to develop new designs with the following aspects in mind:

(a) Disaster characteristics – What characteristics are common and unique between the various natural disasters?
(b) Specific design response – How can we design for specific disaster types and contexts? How can we design a shelter that can adapt to multiple types of disasters?
(c) Materials – Are the materials used suitable for the location and type of disaster?
(d) Integrated design – What essential needs do the shelters provide besides roof and walls? How reconfigurable is the design to accommodate individuals and families?
(e) Responsive and adaptive design - How would the shelters respond and adapt to unpredictable and dangerous new conditions?
(f) Design optimization – How can the structure be made as light as possible? How can the deployment be made easy to reduce human effort?
(g) Transportation – How will the shelters be brought to the disaster site? See Figs. 1 and 4.
(h) Erection – How will the shelters be deployed on site? Will the actuators be hand-operated or electromechanical?
(i) Reliability – How reliable is the design to guarantee resistance, resilience, and well-being of the user?

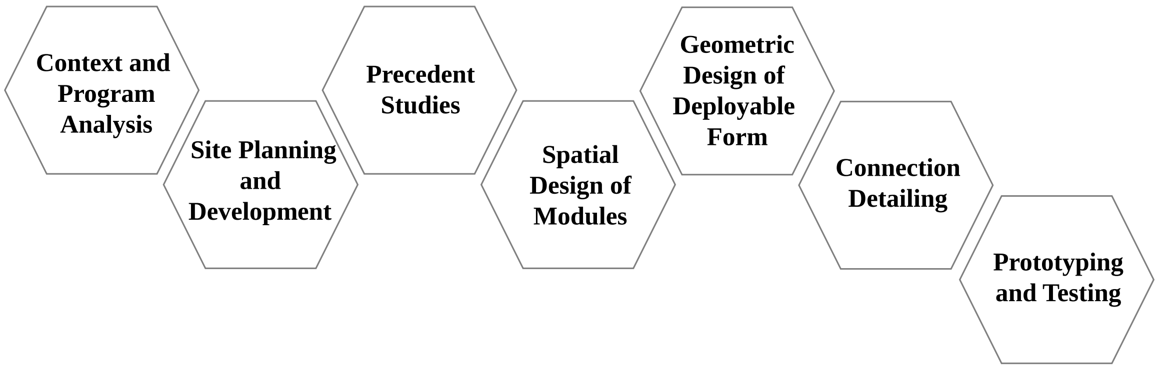


Fig. 3. Architectural design process

The design process would start with disaster and context analysis, followed by site planning and development. Precedent studies as shown in Table 4 should be examined for their potential and limitations. Schematic designs for the specific disaster scenarios should be developed from concept design, design development and through the construction document stages.

The idea is to design a series of modular units that are deployable, thus enhancing the potential for different combinations. As an example, methods to compact a box frame may be studied (Fig. 4b) to achieve maximum compactness when packaging the shelters. Figure 4c shows how a single unit may be expanded to form spaces to shelter larger families. Clusters of units may be formed with open areas as needed to eventually form smaller communities. Single units, multi-units and clusters (Fig. 4c) should be designed integrated with essential facilities such as toilets, cooking counters, and rest spaces.

Geometrical, mechanical and structural aspects should be simultaneously addressed. Foldable geometries, based on geometric and kinematic principles, may be designed using scissor-type mechanisms and origami-based folding techniques. Connections may be unforgiving in the deployment process and would need to be carefully designed. Only accurate geometric design along with detailing can ensure reliable mobility. The design should also impose minimal effort and technical know-how for deployment by the users.

Computer simulations for structural and environmental performance analyses would provide useful insights to improve the designs. Structural analysis and design can be done using the commercial program SAP2000 or any other robust finite element program. The environmental performance analysis, i.e., daylighting, ventilation and acoustic analysis may be accomplished using Grasshopper and its plug-ins.

Making table-top scale models and prototypes should be part of the process. The “learning by making” approach is essential for full understanding of the mobility of a designed structure and the coherent motion of parts of the structures designed.

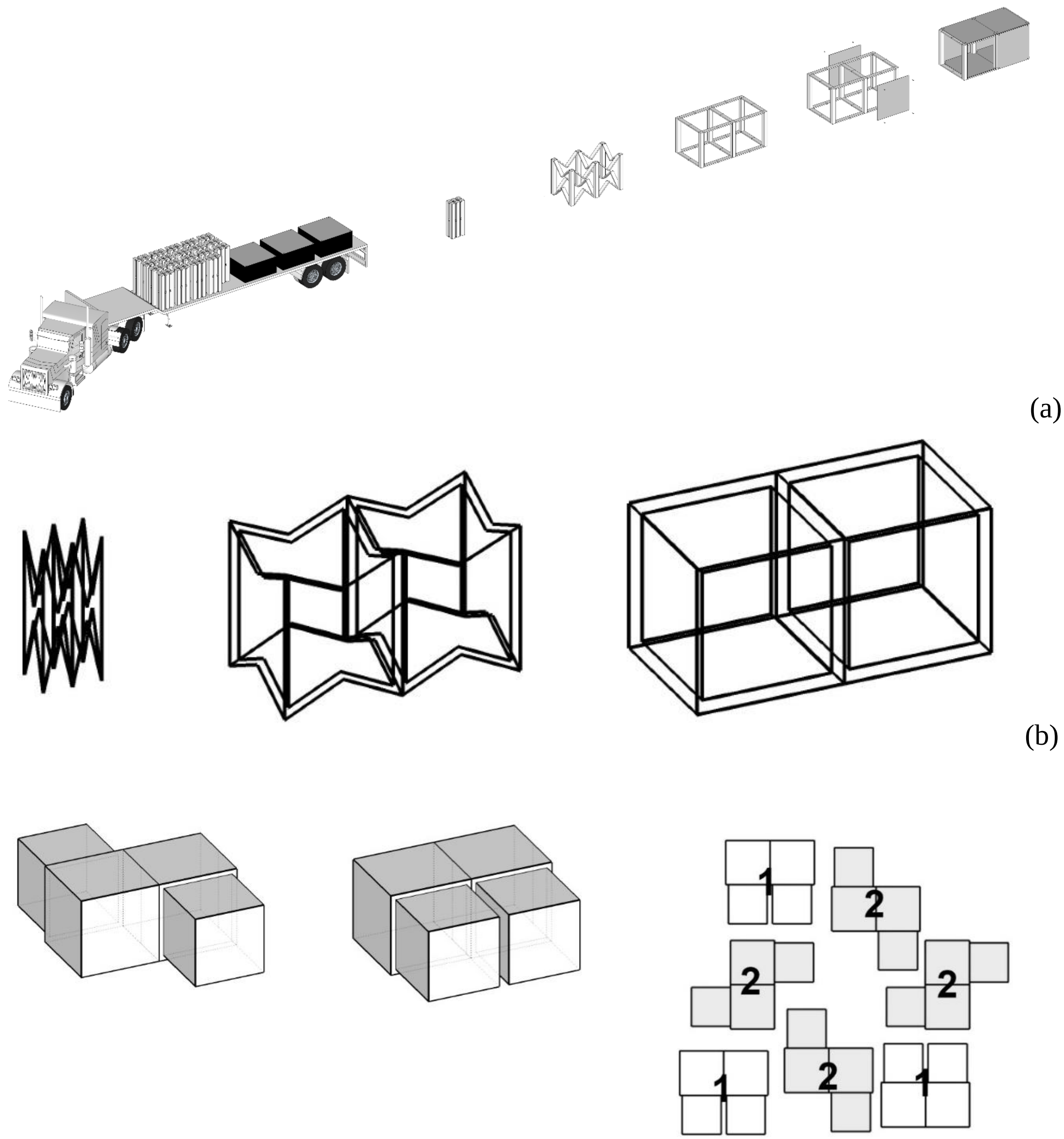


Fig. 4. Schematic diagrams showing (a) packaged units transported and deployed; (b) deployment stages of a modular unit; and (c) multi-family units and clusters by expansion of the basic modular unit.

Conclusions

(1) Transdisciplinary knowledge that includes the study of disasters, disaster management, deployable structures and integrated design strategies is essential for disaster education of society and to cultivate resilient communities. In this spirit, the design of disaster-relief shelters has to be popularized into mainstream architectural education in the form of design studios and seminars.
(2) The outcome and deliverables from the design studios and seminars may be developed as an educational framework to guide the study and design of emergency shelters. This may be in the form of user-friendly programs that can be accessed through city and community libraries. Hands-on activities and workshops on making foldable structures and modular constructions would raise the importance of the subject and add value of user participation in the process.
(3) Knowledge of disasters along with shelter design would empower communities to cope with disasters and construct/reconstruct safe and resilient shelters.
(4) Shelter design would give students a higher purpose of serving local communities while engaging the public in participatory learning.

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