Rapid-response architecture: **Redeployable trauma centres for post-disaster response**

In the wake of global disaster, there is a strong need for post-trauma emergency structures. A research project from South Carolina's Clemson University seeks to inject some architectural integrity into current models

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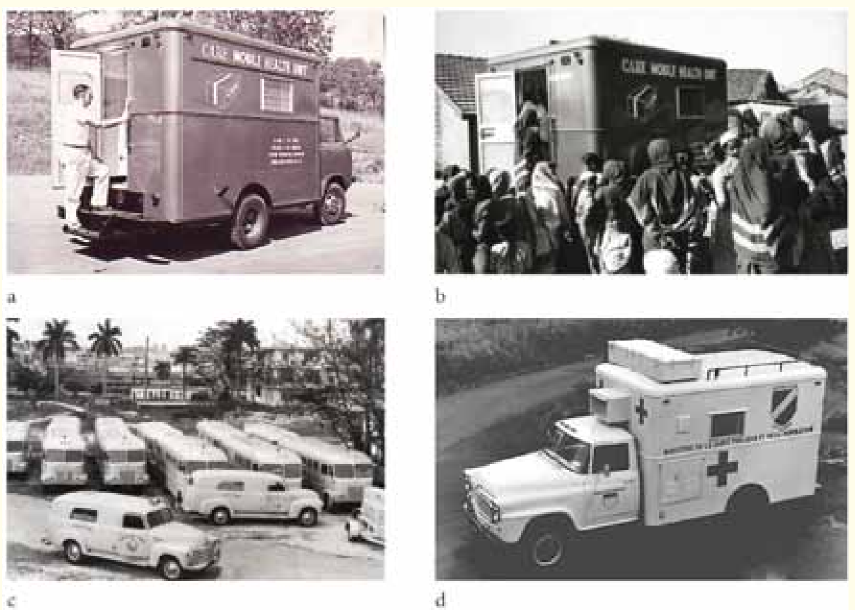
Globally, the rhythms of everyday life are being upturned by unplanned major events. These events may appear to be random occurrences but are increasingly difficult to respond to effectively. Effective, compassionate responses are often unattainable. Geopolitical conflicts, earthquakes, intense hurricanes, flooding, famine, tsunamis, acts of terrorism and cross-cultural ethnic strife over finite, nonrenewable resources are becoming commonplace. With each passing year, in both developed and in less developed societies, citizens are at greater risk. In the US alone in 2011, there were 12 disasters that each caused over $1bn in damages, causing the loss of many hundreds of lives. In Bangladesh in 2011, more than 60,000 internally displaced persons (IDPs) became permanently homeless due to rising seas and corresponding widespread inland flooding that overwhelmed the region's healthcare infrastructure. By 2050, it is predicted that nearly 80% of the world's population will reside in coastal regions and this alone, coupled with increased rises in mean sea levels, warming ambient temperature levels and coastal subsidence, is a recipe for innumerable future disasters.

US Library of Congress

Figure 1: First world war surgical field hospital, France



Medcoach Corp.

Figure 2a-d: Vehicular clinics-on-wheels, 1950s-80s

The need is becoming urgent for rapidly operationalised healthcare facilities able to be quickly deployed to disaster strike zones and set up within hours.[1] In this regard, the World Health Organization (WHO) advocates research and development in innovative, sustainable responses to disasters, including rapid-response architecture. This, in a world where more communities and regions are now increasingly susceptible to the deleterious outcomes of life-altering events of cataclysmic scale and intensity.

Background and recent history

The earliest portable building is generally considered to be the yurt, an ancient thatched hut that could be assembled/disassembled and transported from place to place using carts drawn by mules, oxen or horses. Variants on this basic freestanding building type evolved through the centuries in response to local culture as well as climatic factors, locally available materials, fabrication techniques and site conditions such as mountainous terrain versus low-lying coastal sites.[2]

Currently, modern redeployable trauma centres, or RTCs, are called for, able to be transported and operationalised quickly in the aftermath of man-made and natural disasters globally. Effective, sustainable RTCs can fill a critical void in a community or region's damaged or destroyed healthcare infrastructure. During the first world war, innovations in military hospitals were introduced on the battlefield. New, nomadic systems for healthcare delivery were highly efficient, mobile and relatively lightweight. Lessons had been learned from the American Civil War tent hospitals in this regard. By the first world war, soldiers were sustaining more severe wounds than ever before in combat due to the use of increasingly lethal weaponry. One Mobile Field Hospital, no.353 of the 80th Division, US Army, was deployed in France in 1917; it consisted of 20 tents, and was transported in 40 trucks with convoys stretching as far as a quarter mile in length (Figure 1).

Infirmary trains were another type of RTC utilised in WWI. These British units were highly elaborate and were transported across conventional rail lines up near to the battlefront. A single rail car housed 33 beds for "inpatients". A typical unit consisted of eight types of rail cars with each fitted for a specialised function. Up to 50 cars were deployed in a single train. An allied nomadic type, modern hospital wooden barge RTCs, dated from the American Civil War and were used on canal and rivers: most of these infirmaries had been adapted from agricultural or merchant marine uses. The patient was typically carried on a stretcher across a gangplank to topside and then brought down below deck. These portable vessels, at best, had small portal windows and poor ventilation. Later, massive US hospital ships would be developed, such as the USS Hope. This RTC ship-hospital was deployed in the Persian Gulf and Iraq wars and in 2005 was deployed on the Mississippi River at the New Orleans riverfront in the aftermath of Hurricane Katrina.

During the second world war and throughout the US Korean War, numerous MASH (Medical Army Surgical Hospital) RTCs were implemented in the field near the battlefront. In the Vietnam War, MASH units, together with inflatable MUST (Medical Units Self-Contained and Transportable) were developed for the field. The latter featured a double-walled fabric membrane skin that was inflated by turbine U-packs. These supplied critical HVAC support. While innovative on a tectonic level, they would unfortunately fall victim to collapse from being hit by a single mortar shell; furthermore, they required concrete pads to keep from floating away in tropical rainstorms.

More recently, the US military developed its DEPMED (Deployable Medical) centre transportable system, whose modules were conceived to replicate as closely as possible the functional amenity and stability of a standard brick-and-mortar hospital. DEPMED RTCs employ a variant on standard intermodal shipping containers, and these containers house critical components such as labs, radiology, pharmacy, sterilisation units and surgical suites. The US DEPMED units are interconnected to TEMPER (Tent, Expandable, Modular, Personnel) units consisting of inpatient wards and related support operations. Collectively, these CSH (Compact Support Hospital) units are deployable in a 16- to 256-bed capacity. DEPMEDS, however, are far less mobile than their MASH precursors. For this reason, they are not positioned in direct proximity to frontline combat zones. DEPMED/CSH RTCs have performed rather admirably during the Iraq and Afghanistan Wars, saving thousands of lives.

Ryan Ramsey/S Verderber

Figure 3: Land/amphibious RTC prototype (2012)

Mobile vehicles developed during this period include advanced ambulances, and mobile vehicular clinics-on-wheels in large-scale screening and vaccination campaigns waged against TB in the 1950s and 60s.[3] Numerous corporations in recent decades have manufactured nomadic "clinics-on-wheels" for use by governmental and NGO healthcare organisations, and a wide array public health agencies. These include Ian M Smith's CARE Mobile Medical Clinics, deployed in India in the late 1950s and early 1960s (Figures 2a and 2b), the government of Cuba's deployment of 36 multi-phasic mobile medical units (Figure 2c), and a fleet of 42 mobile health screening units deployed throughout the Republic of Congo in the 1980s (Figure 2d). Not ironically, the hospital bed itself remains that most mobile of devices, and this portability alone provides enticing opportunities for innovative applications in RTC settings.

Recent disasters and RTCs

At the present time, a complex and often contradictory set of six superordinate dimensions generally shape current

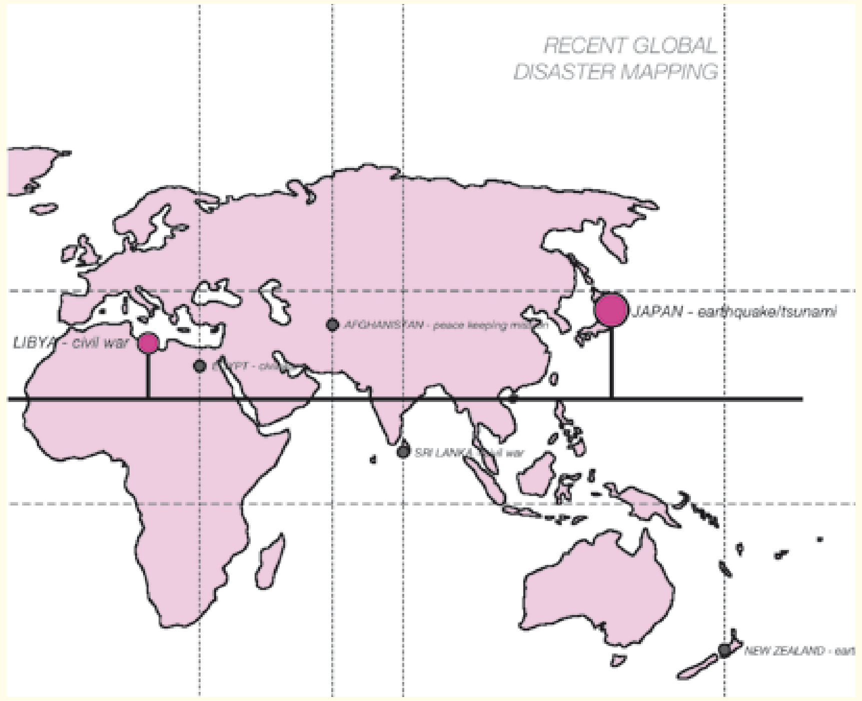


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Figure 4: Recent global disaster mapping

design theories, strategies, and principles, which govern the manufacture of RTCs globally. Each of these broad-based factors manifest in a pre-disaster versus a post-disaster condition, as in the case of *Socio-cultural* factors (demographics, migrational diasporas, religious cycles and traditions, activities of daily living, and quality of life factors as these correlate with human health outcomes).

Political factors include legislation, political systems and their governance models, events of unrest and/or insurgency, issues surrounding political control, the role of capitalist disaster-interest lobbying groups, the role of non-governmental organisations (NGOs), as well as the sense of hope versus apathy, or despair, among the victim populations.

Economic factors include the exchange and control of capital, goods and services, supply and demand issues at the macro and local level, production and distribution systems and their efficacy, and land valuation and demolition trade offs within disaster strike zones.

Climatic factors include local weather, seasonal cycles, and the effects of global climate change. Geographic factors include local geology and soil conditions, topography, plate tectonics, especially in coastal zones, and the influences of hydrological systems. Ecological factors include environmental health, mediation issues, site resilience, and interdependency, diversity, and wellbeing of crops and animal species and their availability as local food sources in the aftermath of disaster.

Hurricane Katrina in 2005 stands as the costliest natural disaster and one of the five deadliest hurricanes in the history of the US, having inflicted the loss of 1,837 lives in subsequent massive floods in New Orleans and along the US Gulf Coast, and incurring over $200bn in property damages. Among recorded Atlantic hurricanes it is the sixth strongest overall. The most deaths occurred in New Orleans, which flooded up to 80% as the city's federally built and maintained levee system catastrophically failed. Large tracts of neighbouring parishes also became flooded, and the toxic floodwaters lingered for weeks. Massive governmental incompetency characterised the entire response to Katrina from top to bottom. RTCs set up in Katrina's strike zone included two massive hospital ships, including one deployed from Canada, and another ship deployed by the US Navy, and the Carolina MED-1 vehicular-based trauma treatment centres, as well as half a dozen US Red Cross open-air tent clinics.

The Haitian earthquake of 2010 was a catastrophic magnitude 7.0 disaster event, with an epicentre near the town of Léogâne, approximately 25km (16 miles) west of Port-au-Prince, Haiti's capital city. An estimated three million people were impacted by the quake; 316,000 lives were lost, 300,000 were injured and more than one million persons instantly became homeless IDPs. The Haitian government estimated that 250,000 residences and 30,000 commercial buildings collapsed or were severely damaged.

Makeshift, zombie-like tent cities sprang up literally overnight everywhere in the days and weeks following the catastrophe. Golf courses, vacant lots, parking lots – in short, anywhere with open space became encampments.[4] They each ranged in size from a few dozen families to thousands of families each. One of the hundreds of temporary-permanent encampments was set up in Corail, eight miles north of the centre of Port-au-Prince. Within days of the earthquake, thousands of refugees had agreed to relocate to this formerly remote, barren place. RTCs set up in the aftermath of the earthquake included an advanced portable hospital sent over by the Israeli government (The Israel Defense Forces Medical Corps IDF-MC Field Hospital), International Red Cross open-air tent hospitals, the ad hoc conversion of schools and residences into makeshift trauma treatment centres, and various container clinics set up by a handful of NGOs deployed from various countries.

The earthquake and tsunami off the Pacific coast of Tohoku in 2011 was a magnitude 9.0 undersea mega-thrust event. It was the most powerful known earthquakes to have ever hit Japan, and one of the five most powerful earthquakes in the world overall since modern record keeping began in 1900. It triggered powerful tsunami waves that reached heights of 40.5 metres in Iwate Prefecture, and which travelled 10km (six miles) inland in the Sendai Region.

In 2011, the NHK News Service in Japan reported that in addition to the loss of 15,800 lives, 5,900 injuries, 3,600 missing persons, and the total destruction of 45,000 buildings, damage to an additional 144,000 buildings, and massive destruction of infrastructural amenities, the tsunami itself inflicted multiple nuclear accidents. These accidents centred on an ongoing Level 7 meltdown at three reactors within the Fukushima I Nuclear Power Plant complex, with associated evacuation zones uprooting the lives of 300,000 IDPs. With remediation and reconstruction exceeding US$300bn, this is at this writing the most costly global disaster on record.

Right after the earthquake, one Japanese architectural firm, Yasutaka Yoshimura Architects, developed a prototype container-shelter, the Ex-Container Project, for persons and families displaced by the disaster. These modular units were extremely generic and minimalist and are adaptable for use as clinics. Their proportions were virtually identical to standard intermodal shipping containers. They are all white on the exterior, with windows and openings sparingly carved out from these "shoeboxes". The modular units can be stacked on top on one another up to four levels in height. They are currently in mass production and a total of 50,000 have been purchased by the Japanese government to date, for deployment across the post-disaster strike zone on newly acquired land parcels. RTCs deployed in this strike zone have to date consisted of International Red Cross and Red Crescent tent Hospitals, airlifts to urban medical centres, and Japanese defence force portable field clinics.

Global prototyping

On the evening of 20 April 2010, a massive explosion occurred in the Gulf of Mexico 60 miles off the coast of Louisiana. An immense ball of fire erupted high into the clear night sky as 11 men lost their lives. An over-budget, problem-plagued deepwater oil exploration platform had imploded – the BP Deepwater Horizon.

The limitations of extreme engineering technology were laid bare for the world to witness as this rig fell 150 metres to the ocean floor, in ruins. For three months thereafter, its ruptured wellbore spewed more than 200m barrels of crude oil directly into the ocean. The unprecedented damage inflicted upon the region's delicate aquatic ecosystems, its seafood industry, tourism, and the communities directly impacted, garnered extensive media attention and scrutiny by global environmental advocacy organisations. Governmental agencies with supposed regulatory oversight of the US deepwater drilling industry were caught completely unprepared.

In response to this and other on-shore and offshore disasters, a prototype RTC was developed within the Graduate Program in Architecture + Health at Clemson University in the US, by Team 896. This system is modular and can be set up on water within a buoyant aperture, configured up to 75 modules, or on dry land. It was developed in response to the specific scenarios of the recent BP disaster, the Tohoku earthquake, and recent strife in the Mediterranean off the coast of Libya (Figures 3-7). This system's modules feature photovoltaic panels, lightweight shell fabrication based on techniques perfected by the automobile industry, and a thermoplastic polymer exterior "skin" (Figure 7). Ryan Ramsey co-lead the design of this innovative prototype (with the author).

The RTC's configurations can be pre-set to be expandable from a single modular unit to as many as 75 or more modules on a single site. (Figure 5). The most anticipatory of these systems afford a high degree of flexibility from a site-planning standpoint. Reconfigurability options yield pinpoint response modalities in settings that can range from dense urban, open shoreline, irregularly shaped sites, to remote rural sites. In terms of design/tectonic and installation factors, modular systems, lift-pack systems, and hybrid systems combining elements of both, are most feasible at this time. Hybrid pneumatic combined with hybrid fixed container systems likely afford the most amenity and flexibility in most field settings. In Israel, two large urban

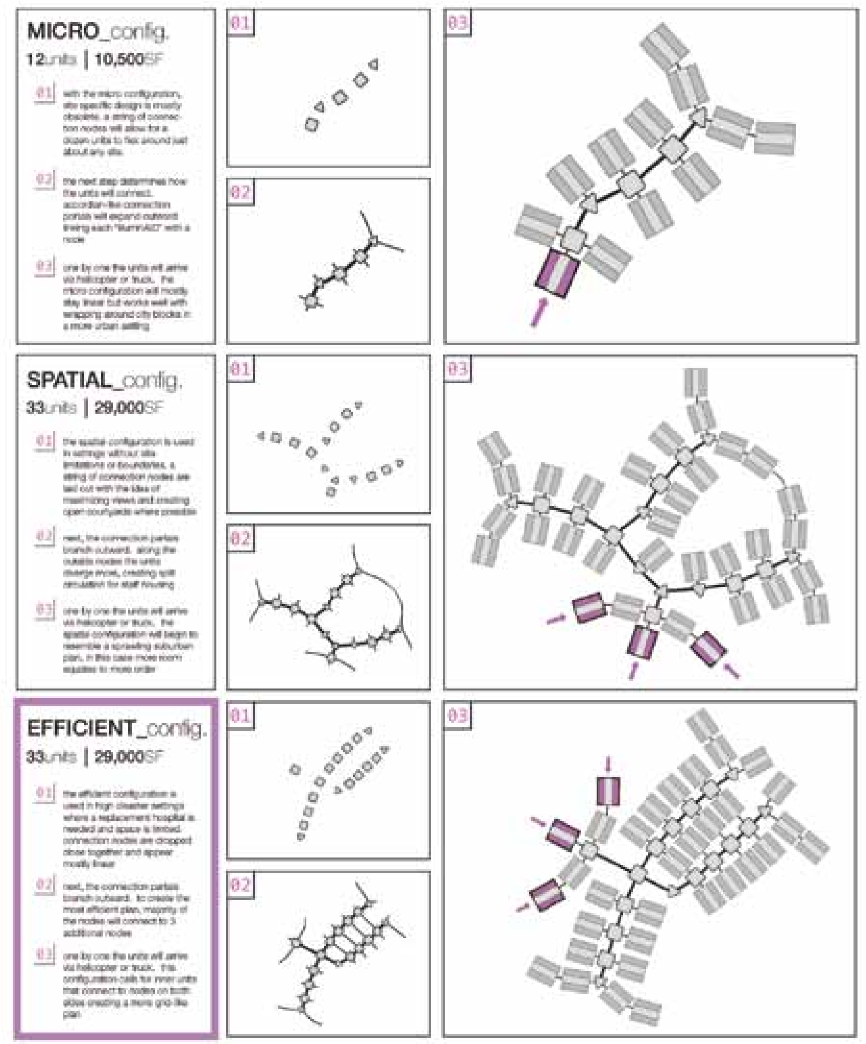

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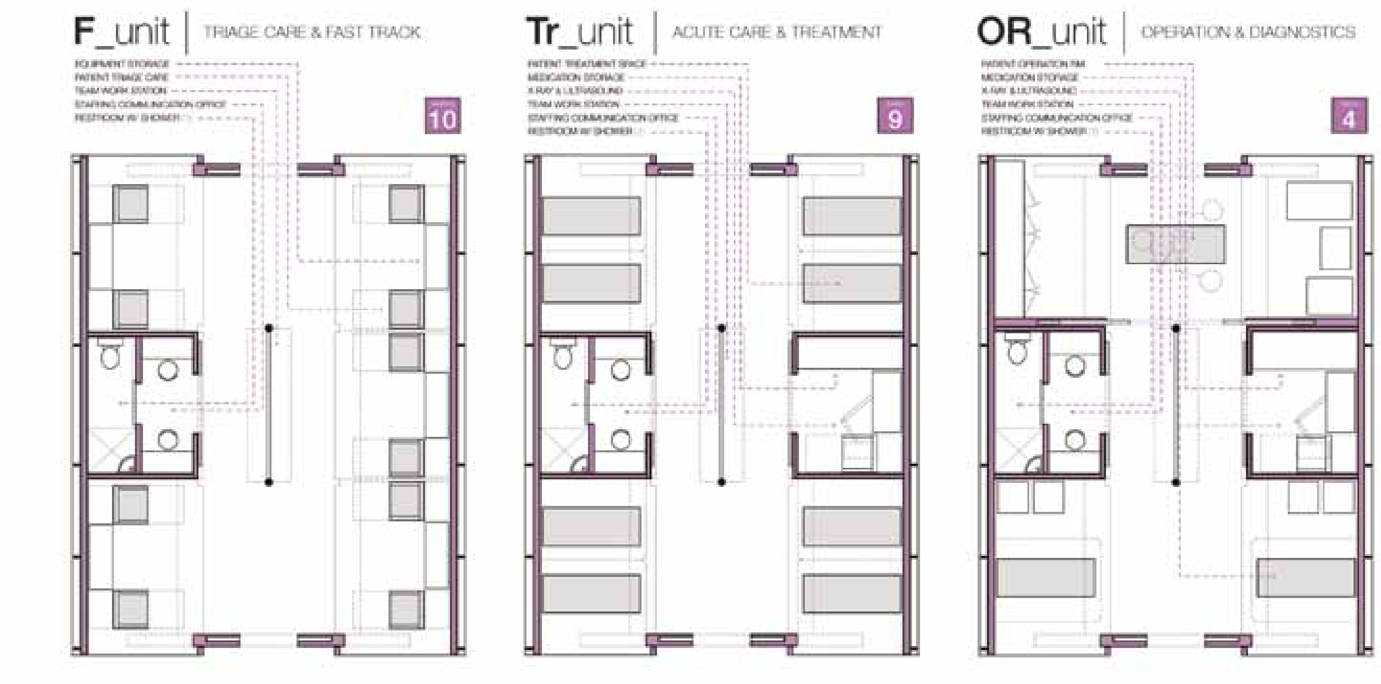
Figure 5: Suggested configurations for the prototype, according to site limitations and level of disaster



Ryan Ramsey/S Verderber

Figure 6: Internal configurations can be adjusted according to need – from surgery space to staff housing

hospitals recently opened, each with a below-grade parking deck that can rapidly be re-deployed/reconfigured to house pop-up portable trauma centres (Figure 8). This strategy is one that warrants significant further research and field testing.[5]

It would appear logical to surmise that the global demand for ecologically sustainable and health-promoting RTCs has never been greater. Of course, challenges and opportunities associated with RTCs are many, as are the various methods available for their funding, designing, prototyping and manufacture. An RTC can function as a freestanding entity, or as an adjunct to a fixed, immobile healthcare infrastructure, including as kit-of-parts, highly flexible appendages to conventional, fixed-site clinics, hospitals and medical centres.

Why aren't more architects engaged in responding to the challenge? Why is it that so few off-the-shelf prototypes of genuine architectural integrity are readily available for first-responder implementation? Where is private industry? Why have most healthcare architects remained indifferent to this call for action? The following are perhaps a few reasons why significant architectural design/tectonic advancements in this field remain so few and far between:

The dominance of the engineers: Transnational engineering firms dominate the industry as the provider of first choice in emergency and offshore shelter. An emphasis on bare bones functionality and logistical expediency has usurped any attention to anything that might be equated with the broader, classically based Vitruvian principles of architecture (commodity, firmness and delight). The largest US federal contracts are held by a relatively small handful of very large engineering corporations.[6] These politically connected corporations tend to dismiss anything that aspires to achieve more than bare functionality: "We don't have time for architects (or architecture) and they are (it is) a needless expense anyway that just slows us down."

Architects' traditional disdain for bureaucracy: Many architects are disinclined to communicate with engineers and politicians in a truly collaborative spirit. It is this fact that perhaps holds the profession back from making further inroads in achieving higher healthcare design quality with respect to pre-manufactured RTCs. This might account for the disaster industry's unfortunate yet continued overreliance on prosaic, uncreative and excessively minimalist shipping-container-based systems, nearly all of which are placeless, inflexible and wholly generic in relation to the timeless Vitruvian principles of commodity, firmness and delight.

Lack of professional training and preparation: The culture within most academic schools of architecture does not foster a genuine appreciation for or attitude of social engagement among the students – in terms of inculcating the personal initiative, sense of compassion and indefatigable perseverance so necessary to respond quickly and adroitly to healthcare needs in the aftermath of disaster. It is not an overstatement to say that, while in school, most architects are not trained to communicate with NGOs, with civil engineers or the aforementioned for-profit mega-corporations that specialise in disaster mitigation, nor with governmental ministries of health. The status quo in this regard must change, and change quickly.

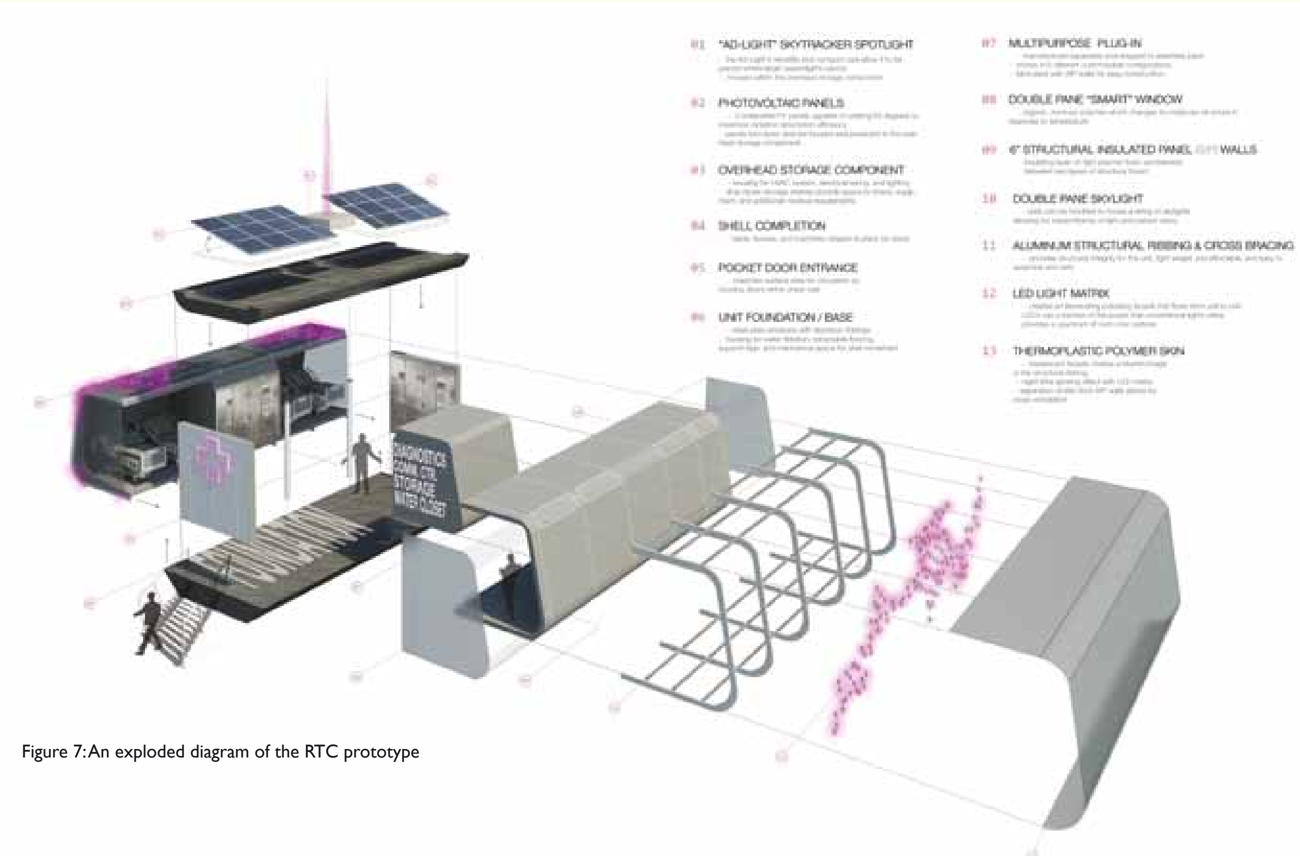


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Figure 7: An exploded diagram of the RTC prototype

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Figure 8: Israeli RTC deployment within medical centre parking deck

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