Progressive Housing with Permanent Core Dwelling resistant to Natural Hazards

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Biography of Presenting Author: He has been working during many years with different IGOs in and around the building sector in some twenty countries in Africa and Asia on both micro and macro level, and carried out construction sector studies in several countries. He started researching on the primary/secondary effects of habitat hazard-disaster causalities in developing countries several years ago, and developed the presented container core-dwelling concept. Later, he collaborated on this subject with Prof. Nussbaumer from 2011 to 2015. He holds postgraduate degrees in Architecture, Civil Engineering, and Business Administration.

Abstract:

The present situation with an accelerating population growth worldwide will generate unprecedented demands on several crucial supply factors including shelter, especially in developing and underdeveloped countries. And as many of these countries are regularly exposed to natural hazards that frequently turn into disasters, this project has identified as a logic consequence to focus the research on securitising the habitat. A safe habitat in these countries is of fundamental importance and necessity to allow for a dynamic growth of the grass-root and full economies. And economic strength is of major importance to solve other crucial supply problems.

The objective of this ongoing research project is to propose architectural and technical solutions for quality guaranteed, new or re-construction by first building a natural hazard resistant core dwelling using recycled 20ft ISO shipping containers, then integrating the core in a progressive owner-driven housing structure. NB it is not concerning container architecture/housing using containers as final residential volumes. The project demonstrates the architectural, structural and risk reduction potential of this solution. Full attention is paid to blend in the structure with the existing culture, and vernacular and prevailing local architecture. The project phases follow an evolution/feedback system of Feasibility ⇔ Implementability ⇔ Adoptability ⇔ Acceptability that will minimize the risks of output repellence.

The paper presents the state of progress of the research project, which deals with the production of first concepts, the outcomes of workshops held at EPFL, in India, in Malaysia about architectural and technical solutions, as well as structural tests on containers with unreinforced openings.

A truly interdisciplinary and international project. The research is implemented in international collaboration between interdisciplinary teams at three universities, whereof two in South-Asian natural-disaster-ridden developing countries with different cultural profiles.

Interdisciplinary-humanitarian student projects. In connection with the research work, the topic is also proposed to undergraduate students as projects at the participating academic institutions.

Keywords: Core dwelling, incremental/vernacular architecture, natural hazards/disasters, grass-root economy, interdisciplinary research.
1. Introduction

The present situation with an accelerating population growth worldwide will generate unprecedented demands on several crucial supply factors including shelter, especially in developing and underdeveloped countries. And as many of these countries are regularly exposed to natural hazards that frequently turn into disasters, this project has identified as a logic consequence to focus the research on securitising the habitat. A safe habitat in these countries is of fundamental importance and necessity to allow for a dynamic growth of the grass-root economy and the full economy. And economic strength is of major importance to solve other crucial supply problems.

This ongoing research project is focused on the usage of a 20ft ISO shipping container as core dwelling resistant to natural hazards within a progressive residential structure (fig. 09-14, 15-18). NB it is not concerning container architecture/housing using containers as final residential volumes.

A truly interdisciplinary and international project, where the multidisciplinarity is ensured by the international collaboration between EPFL and interdisciplinary teams at University of Technology Malaysia UTM, and Indian Institute of Technology Gandhinagar IITGN bringing together a total research strength in the fields of Engineering (several specializations), Architecture, and Social Science, and different cultures and traditions in disaster-ridden environmental settings. And where the collaborating interdisciplinary teams have a gender-mixed composition, in order to achieve an optimal contact with the end-users and an over-all information flow.

Interdisciplinary-humanitarian student projects. In link with research work, the topic is also proposed to undergraduate students as projects at the participating academic institutions. At EPFL, this is done within the framework of the “projeter ensemble” (design together) from the ENAC faculty.

2. Research objectives and methodology

Main Objective: A housing system with container core-dwelling resistant to horizontal and vertical forces from natural extreme events and acceptable to end-users.

Sub-Objectives:

- Demonstrate the safety of a core of modified 20ft ISO shipping container(s) that withstands the impact of natural hazards, more precisely seismic activities and cyclones of a specific intensity. Usable in a single or multi-storey configuration.
- Identify alternative possible modifications to 20ft ISO shipping containers to allow for a maximum of alternative secure user variations.
- Show the acceptability to end-users of a core-dwelling solution, implementable as progressive housing in an incremental architecture applying vernacular, local and traditional housing systems.
- Disseminate the results to key stakeholders.

Methodology. It has shown repeatedly in the past that mono-discipline focused North => South approaches to solve this type of complex problems lead to solutions that are dissatisfactory or quite simply non-implementable. (El-Masri&Kellett 2001) (Hausler 2004). Therefore, this project is based on a balanced North ⇔ South ⇔ South interdisciplinary interaction between academic institutions with specialists in the three disciplines of Engineering, Architecture and Social Science, cf. fig. 21, 22. And it applies an evolution/feed-back system of Feasibility ⇔ Implementability ⇔ Adoptability ⇔ Acceptability that will minimize the risks of output repellence.

The understanding of the structural behaviour of the core dwelling is done by full-scale laboratory tests on single converted containers. Then, the behaviour of what can be assimilated to a construction “brick” is modelled using Finite Element Method FEM and validated against the tests. The full core-dwelling, which can be composed of several containers, can then be modelled. As for the action and action effects of extreme events (i.e. seismic loads, fire, flooding loads), their characterization is made either using regulation requirements, as well as with statistical records on various relevant sites and their analyses to determine the characteristic value of the action. The structural behaviour of housing with permanent core dwelling under seismic loads will be confirmed by laboratory tests on down-scaled models.

The implementability is developed by evaluating the impact of the dialog between structural quality needs and cultural and traditional preferences on the resulting architectural implementations. And contacts are initiated with grassroots’ representation and concerned end-users in presumptive follow-up implementation areas.

The results and the deepening grassroots dialog on adaptability ⇔ acceptability will serve as guidance for the follow-up field implementation in identified areas. All findings are to be continuously carefully analysed by the interdisciplinary teams and serve as a base for the final conclusions. Comparative life-cycle cost analysis (LCCA) is to be used to investigate the sustainability of the container core dwellings.
3. The question at large

Natural disasters

A generally accepted definition of natural disasters does not exist and different definitions have been developed in different sectors of the society. The Swiss official definition of a disaster is “A natural event or a man-made event where the affected community cannot alone master the direct effects.” (OACata 974.03). While the Emergency Events Database defines a natural disaster as a “situation or event, which overwhelms local capacity, necessitating a request to national or international level for external assistance” and “an unforeseen and often sudden event that causes great damage, destruction and human suffering.” (EM-DAT). Types of natural disasters can be classified into five sub-groups, namely Biological, Geophysical, Hydrological, Metrological and Climatological. The numbers of natural disaster occurrences and the cost of damages increased exponentially since Year 1975. Even though the fatality of natural disasters is decreased in recent years (UN-ISDR 2011), the total number of total affected people (injured, homeless and affected) increased dramatically.

It is estimated that the toll of human lives and value of property losses due to natural disasters show higher figures for the thirty-five-year period after 1975 than for the whole century prior to that year. The United Nations estimate that the population will increase from 1950 to 2050 by 359% in the less developed regions, by 734% in the least developed regions, and by more than 335% in natural-disaster-prone regions. The South Asian tsunami in 2004 alone killed some 280’000 people, destroyed some 375’000 houses, and generated total financial losses of about USD10’700 million (Disaster Watch 2005). The earthquake in Haiti 2010 killed over 230’000 people and generated destructions to an estimated total value of close to USD7’900 million. Housing was the sector most affected by the earthquake, given that the total damage was USD2’300 million. (Haiti PDNA 2010).

The World Bank states that the developing countries suffer the greatest costs when a disaster hits – more than 95 percent of all deaths caused by disasters occur in developing countries, and losses due to natural disasters are 20 times greater (as a percentage of GDP) in developing countries than in industrialized countries. (World Bank 2010). Least-developed or simple, less complex economies are typically perceived as most vulnerable. Even though their absolute losses as a consequence of a particular disaster may be small relative to the levels reported in developed countries, the disaster can exacerbate existing problems of indebtedness and poverty. (Benson & Clay 2004). Most natural disasters are recurrent, and the same types of disaster strike the same nations repeatedly. Just as the poorer members of society are getting back on their feet, they often get knocked down again. And recurrent natural disasters force significant diversion of resources from sustainable development. (Parker 2000). And it is primarily the regions with a high population density and a lower level of development that are found to be most exposed to the risks of natural hazards, as can be seen on the maps in fig. 02-04.

From the above, from disaster fatalities by type and level of development, 1991-2005 as given by (Abbas, K.J. et al. 2010) and fig. 01, it can be concluded that hydro-meteorological, essentially floods and windstorms, and geophysical (earthquakes and tsunamis) are the main causes and that the most affected are the Asian developing countries. The disaster risk-poverty nexus in fig. 06 illustrates schematically some of the interactions between disaster risk and poverty. Poor households often have a very limited capacity to access and use assets in order to take disaster precautions and buffer disaster losses. It has been shown (Bhatti 2001) that the burden of responsibility to provide disaster risk information and relief measures has been shifted solely to the state, and existing time-tested conjectures about risk analysis, clan-based reciprocity, community-based coping mechanisms and informal security and support systems have thus been negatively affected or eroded. The vacuum thereby created has not adequately been filled by the state, which has failed its paternal claims in the times of emergency. Ancient methods have supposedly lost their practicality while modern tools, for an effective execution, have yet to establish their cultural relevance and functional compatibility with perceptual selectivity of at-risk communities.
Fig. 02. Highest World Population Density (source: Center for International Earth Science Information Network)

Fig. 03. Advanced, transitioning, less and least developed countries (source: Wikimedia, based on the CIA World Factbook, IMF and UN definitions)

Fig. 04. Earthquakes (brown) and cyclones (green) (source: UN-ISDR/Munich RE)

Fig. 05. Corruption cleanliness in % (source: Transparency International 2014)
Furthermore, fatalism is one important point of reference in rationalizing disaster and is believed to be the enemy of initiative and can inhibit the instinct of self-preservation essential to survival. And a cross-cultural analysis of natural disaster response showed a high correlation between religious influence and cultural behaviour. (Marinicioni 1994).

As a result of an increasing population, land areas that were previously not developed for or not considered suitable for residential purposes due to hazardous risks are to an increasing degree being planned legally or occupied illegally for residential purposes. The risks are further accelerated by manmade hazards e.g. deforestations generating a climatological imbalance with vulnerability to flooding, erosion and landslide, and destruction of coral reefs by fishing with dynamite or by extracting building material, generating an exposure of ocean coast lines to flooding by hurricanes and tsunamis. So, the experience shows today that the natural hazards more frequently turn into disasters of an important magnitude with a high toll of human lives and loss of housing. And the estimates indicate a continuous concentration of population in areas exposed to natural hazards with an increasing risk of disasters as a consequence, further accelerated by manmade hazards. It is therefore of importance and urgency to research into ways of limiting the effects of possible natural hazards so that they do not turn into disasters. Taking into account that the residence is the focal point of daily life and social stability, especially in these regions, it is logical to focus the research on improving the housing quality in order to provide an optimal security against natural disasters. (Sandberg 2010).

Fig. 06. The Disaster Risk-Poverty Nexus (UN-ISDR 2009; Abbas, K.J. et al. 2010)

**Impact of corruption on construction cost and quality**

A study shows that 83% of all deaths from building collapse in earthquakes over the past 30 years occurred in countries that are anomalously corrupt. The statistics also support the present widely voiced opinions that the probability of earthquake-related deaths is less a function of geography and more the ability to afford earthquake-resistant construction and to enforce building codes. Complex administrative construction processes lend themselves to corruption by implying or requiring bribes before officials sanction stages of the processes. And administrations that are not already complex, can be made so by officials impeding the progress of documentation until bribes have been paid by applicants. See further fig. 05, 07 and 08. (Lewis 2008). (Ambrasey&Bilham 2011).

By experience, there are countries where the corruption can reach some twenty percent. And there are countries where Government funded construction projects pass through some sixteen stages from concept to handover, and are severely affected by corruption of up to thirty percent of total value, with the focus being on the tendering stage of between fifteen to twenty percent. It is obvious that corruption of this magnitude in the interface between the public and private sectors cannot be covered by any built-in profit margin, overestimation of additional work or streamlined operation approach alone, but can only be by cuts in quality and quantity affecting the end-user. (Sandberg 1999).
Experience from large-scale disasters around the world has shown that an in-situ owner-driven and community-driven reconstruction model is highly effective and can save 40 percent comparing to contractor-built housing. This model is also faster to implement and has a significant economic multiplier effect. (World Bank 2014).

**Fig. 07** | **Cash and corruption.** The poorest countries are the most corrupt, but some are more corrupt than others. A weighted regression line (dashed) divides nations that are perceived as more corrupt (below the line) than might be expected from the average income per capita from those that are less corrupt (above the line). Named countries have lost citizens in building collapse caused by earthquakes since 1980. (Source: Ambrasey&Bilham 2011)

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**Fig. 08** | **Corruption's toll.** Corruption versus the level of corruption that might be expected from per capita income. Of all earthquake fatalities attributable to building collapse in the past three decades, 82.6% occur in societies that are anomalously corrupt (left-hand corner of the plot). (Source: Ambrasey&Bilham 2011)
Other post disaster reconstruction studies in developing countries do also prioritize the owner-driven strategy. (Davies 2012). And comparative research analyses of government driven, donor driven, and market driven reconstruction strategies were carried out in China, Indonesia, and Australia. It was found that all three systems showed serious handicaps in project implementation. (Chang et al. 2010). But studies also show that owner-driven re-/construction programmes, although including information and training, do not always reach a satisfactory quality resistant to natural hazards. (Hausler 2004, Chamberlain 2015).

Thus the optimal strategy is to apply an owner-driven quality-guaranteed model with a simplified administrative construction process, and thus maximising possible savings and minimising exposure to corruption.

4. Current state of research in the field

Permanent Core Dwelling resistant to Natural Hazards

Developed countries have a high level of available organizational capacity and resource density, thus making them stable even to disasters and emergency events. In less/least developed countries, this is not the case because the already weak organization and few resources during normal circumstances tend to be totally paralyzed during and after a disaster. Delays in shelter provision increase vulnerability of the refugees to social problems such as crime rate increase by looting, robbing, physical threats etc. as happened in US New Orleans 2006 hurricane Katrina, Haiti 2010 earthquake, and Philippines 2013 typhoon Haiyan. Good quality building materials can be difficult to find in developing and under-developed countries under normal circumstances and totally absent post-disaster. Focusing the improvement of the housing quality to withstand a wide spectrum of natural hazards is thus of paramount importance; it gives the house occupants a safe base for self-help and participation in community support. In short, focusing on a natural-hazard resistant solution that is implementable at any time during the hazard cycle.

When disaster situations affect developing countries, the current status-quo for shelter relief is to import pre-assembled tents or tarp materials to accommodate immediate shelter needs. Following this emergency phase, organizations often construct individual transitional shelters. (Ahbas et al. 2010) (Prinz&Nussbaumer 2014). These transitional shelters are being criticized for being too late, too expensive, in contradiction to local culture and living needs, not sustainable, and generating long-term environmental and social economic damages (Johnson 2007; Caia et al. 2010; Dilanthi 2011; Félix et al. 2013; Barenstein&Leemann 2013). Urge for an improved temporary house design is needed, with (ideally) immediate availability, rapid and simple construction, open-ended design adaptable to local social and cultural needs, pre-designed for long-term usage (reusable structure and structure’s second life), cost effective (utilize local labour and technology) and environmental friendly (Johnson 2007; Félix et al. 2013). In short, a low-cost, low-tech and low-maintenance solution of guaranteed quality.

The PDR Guidelines from International Federation of Red-Cross Red-Crescent Society gives the following definition of Core shelters / One room shelters. - Post disaster household shelters planned and designed as permanent dwellings, to be the part of the future permanent housing, allowing and facilitating the future permanent housing, as well as allowing and facilitating the future process of extension by the household, following its own means and resources. The aim of a core shelter is to create one or two rooms, providing safe post disaster shelter that reaches permanent housing standards, and facilitates development, but not completing a full permanent house. (IFRC 2011; IFRC 2013; UN-HABITAT 2012)

In conclusion, an optimal approach would be to apply design criteria that produce a core dwelling unit that:

- withstands a wide spectrum of natural disasters;
- is a low-cost, low-tech and low-maintenance structure of guaranteed quality;
- can be promptly implemented as a transitional dwelling at any time during the hazard cycle, and progressively be upgraded and expanded to permanent living standard while inhabited;
- is omnipresent, readily available on an industrial scale, and with minimum corruption exposure;
- allows for a flat hierarchy on the grass-root level with owner-driven self-help schemes in the transformation process from transitional to permanent housing standards;
- makes it possible for all available resources in the society to participate during the recovery period;
- is easily implemented on a large scale in different regions by any concerned authority or agency.

The only such structure available worldwide today is the standardized shipping container produced in accordance with the ISO norms. And in consequence in this context, container structures have been identified as a solution of interest to further explore. (Sandberg 2010).
ISO Shipping Container, Core Dwelling for Natural Hazard Protection and Post-Disaster Reconstruction

ISO shipping containers are engineered in accordance to ISO standards, able to cater loads to different modes of transport (ship, truck, train, towing etc.) and have unique stackable chassis. This core-dwelling concept will allow the occupants to individualize and expand their living space in up to five directions (fig. 09). Proof is of importance, of the resistance of the system created to natural hazards, mainly to earthquakes, hurricanes, and floods. Until now, there were no valid models for the strength of modified ISO shipping containers to withstand natural hazards. A study used computer modelling of a 20ft container in a combination of eight different container configurations and five different loading scenarios to decide displacement at maximum applied force at yielding. The scenarios were modelled on removing whole sides or roof of the container to study the influence of large openings. (Giriunas 2012). Thus the study is of some interest since the scenarios can be used as lower and upper bounds before testing of containers with openings. It however does not match the core dwelling profile. Other computer modelling and full scale studies have been made on the impact of floating containers against static objects during floods, tsunamis etc. (Aghl et al 2014, 2014a, 2015). These studies are of little interest as they were carried out on unmodified containers and to evaluate the damage made by the containers, not to them. A series of studies have been made on element joints and different housing designs using cold-formed steel structures resistant to seismic activities. (Chu et al 2010, Chu&Yao 2010, Liu&Guo 2010, Yao&Chu 2010, Wu et al 2012, Zhang et al 2013). These studies are not applicable due to the special chassis design of the container, but cold-formed elements can be used for extending the house and thus may be an area of study in the future.

5. Current state of our own research and project implementation

Our first works on rapid post-disaster rebuilding in developing regions using steel were presented at the Tech4Dev2012 (Prinz&Nussbaumer 2014). The focus is on the habitat and does not include WASH (water, sanitation and hygiene) and infrastructure. Among the propositions made, the main one was to study the idea of multi-story, multifamily, locally fabricated shelter concepts and fast rebuilding technologies suitable for urban environments.

The project expanded and started a multi-disciplinary collaboration with Indian Institute of Technology, Gandhinagar IITGN and University of Technology Malaysia, Johor Bahru UTM; both institutions are situated in S-SE Asia, regions especially prone to natural disasters (fig. 02-04). This collaboration has resulted until now in three workshops focusing on the use of the 20ft shipping container as a permanent core dwelling within a progressive housing, entitled ‘Containers for Housing and Re-Urbanisation in post-disasters context’ with participation from different disciplines of the academic, private and public sectors in Switzerland, India and Malaysia. The first one was held at EPFL in Nov. 2014, the second one at IITGN in Aug 2015, and the third one at UTM in Nov. 2015. The main outcome of these workshops and ongoing works are the following:
- Interactions between disaster risk and poverty, secure core-dwellings to create a resilient society, see current state of research.
- Impact of corruption on construction costs and quality, good reason towards containers and owner-driven solutions, develop a prototype progressive housing that uses the 20ft ISO shipping container as the core-structure, see figs. 09-14 and fig 15-18.
- Post disaster in any sense, including also manmade ones. Preferably container core dwellings to be used in low and medium dense development areas. Could initially be used as transportable temporary dwelling, but should soon be finally positioned as progressive housing in order to minimize discomfort.
- A container core-dwelling should overcome the current rapidity-quality problems, and fulfill the requirements from architecture, engineering, social science, and emergency aid organization (and e.g. UN-Habitat, Shelter Centre) perspectives, see below, and figs. 21, 22. In other words, need to consider 3 main issues: acceptance, technology, implementation, and if all three are not raised at the same time, project will fail.
- Urban planning with containers as unit, significant numbers, could lead to new urban design and should be an area of research.
- Containers as shelters are acceptable, even desired, by people after a natural disaster (see paragraph on acceptability below) but more as a short-term solution. Also possible in urban contexts (multi-storey possibility) and in countries with coastal regions. Need normal communication, container core-dwelling is not container living, it is only the core of future larger housing. For example, student projects were initiated to help with this issue.
- During shelter phase, study of the best low-cost low-tech solutions for shading and ventilation to avoid overheating inside is of paramount importance.
- Openings shall remain small initially, at least during the shelter stage, for safety and protection of people and belongings inside the container, see fig. 19.
Fig. 09-14 First concepts of evolutions of a progressive housing with one permanent container core resistant to natural disasters.

Fig. 15-18 First concepts of evolutions of a progressive housing with superimposed permanent container cores resistant to natural disasters.
Site visits were made in conjunction with the workshops. In India to the Kutch district that was severely affected by a tropical cyclone in 1998 and an earthquake in 2001. In Malaysia to the Kelantan state that during recent years has been severely affected by heavy rains and floods. The main findings are the following:

- The container core dwelling concept is primarily suitable in low and medium dense areas exposed to primarily earthquakes and/or cyclones, other natural hazards can be considered as secondary risks.
- Remote areas are less accessible and least developed. In consequence such areas are more exposed to disasters and during a longer period, which increases the suffering for the concerned population. A natural hazard resistant habitat solution is of importance.
- Local authorities and village chiefs have a paramount influence on any reconstruction process.
- In a relocation area within town limits initially provided with government built small houses occupying about half the plot, most houses had been expanded to two-three stories and in some cases occupying the whole plot area.
- Earthquake-resistant concrete core dwellings without expansion possibilities built in villages had been downgraded to sheep sheds, store rooms etc. when the owner built a new traditional house; or a new house had been built nearby with half the family living in each, generating segregation problems.
- When relocation post disaster was decided by a geographical, ethnic or religious population group itself, the relocation was successfully implemented, even when moving out from city centre into the country side.
- A government-built lower-class temporary relocation area far outside town limits was positioned next to new industry complexes, transport/warehouse areas and other job creating activities. The area had not been abandoned, had generated also its own infra-sector income-earning services, and was now being upgraded to permanent standard by the government.
- NGO built high quality relocation areas along main arteries far outside city limits prospered and had been further expanded by private developers.

About acceptability, two initial surveys in Malaysia and India were performed at UTM and IITGN on the acceptability of modified containers as dwellings. The first one (Wong 2015) showed that more than 50% of the people feel more secure to live inside a container home than any other type. The second one (Kumar 2015) showed that in a crisis situation and offered the choice, 41% of the people would prefer a steel shelter, 35% a wooden one, 19% a masonry and only 5% a concrete construction shelter. One important popular misconception is that one cannot use cellular phones inside a container. Tan & Lee showed that inside a container with some openings (min. necessary for transforming it into a living space), radio signals are receivable without antenna or relay, similar to inside a van. (Tan & Lee 2015).

It is fundamental to identify acceptable areas and the maximum acceptable size of openings that could be made on containers while safeguarding the minimum required strength and stiffness in reference to the maximum expected exposure to natural hazards. In a first approach, the container structure was modelled with linear material and geometric characteristics and then subjected to defined horizontal actions in orthogonal directions in order to determine its elastic stiffness and load at first yielding (Rabenatoandro 2013) and compared it to literature (Giriunas et al. 2012). It showed that foundation support conditions had a large influence on lateral stiffness values. It permitted to fix first values of allowable max. opening sizes while keeping sufficient stiffness.
In order to confirm the results of the modelling and identify the proper foundation conditions, four full-scale laboratory tests on two containers with different openings were carried out at UTM. An early evaluation indicates that the modified containers behaviour is adequate, i.e. no early failure, nor degradation of elastic behaviour due to openings, stiffness in-between extreme bounds, as can be observed on fig. 19b. The size of the openings, slits actually, is a compromise to satisfy safety and protection of people and belongings, as well as easy to close openings in case of windstorms at the shelter stage, and at the same time serve as initial cutting lines for future doors or windows for later stages.

**Interdisciplinary-humanitarian student projects.**

Finally, in link with research work, the topic is also proposed to undergraduate students as projects at the participating academic institutions. At EPFL, this is done within the framework of the “projeter ensemble” (design together) from the ENAC (Architecture, Civil and Environmental Engineering) faculty. In particular, the topic is used in a so-called ENAC week for second year bachelor students. The students are introduced to work in interdisciplinary groups representing Engineering, Architecture and Environment Sciences. As a result, the students produced urban and housing concepts. They built models of housings with container core and studied the evolution in time (one month, one year, ten years) that are useful to explain the possibilities of progressive housing with permanent core dwelling. (ENAC-02 2015). This is an important balance to the monodisciplinary work on high prestige projects that the students usually are exposed to. And it is a constructive involvement to prepare students to be aware of and take decisions that protect and enhance the quality of life and environment.

6. Discussion

A container core-dwelling offers some advantages over the existing shelter projects, e.g. multi-hazard resistance, multi-storey possibilities, readily available in many ports and in large numbers for quick reaction, reusable and recyclable. Proper design can make the container core-dwelling into being a permanent structure resistant to natural disasters within a progressive housing applying incremental architecture solutions. And the concept will shorten and simplify the recovery process and by that minimize the suffering of the hit population (fig. 20).

![Post Disaster Recovery Phases](image)

Fig. 20. An accelerated and simplified reconstruction process.

The core-dwelling concept will also allow the occupants to individualize and expand their living space in up to five directions (fig. 09), and to individualize and finalize interior and exterior surface materials to blend in with vernacular architecture. The concept will also give an optimal rigidity to the final permanent habitat, something that passed experience has shown being a weak point of owner-driven projects. As was found during the site visits, there must be enough space allocated for the core-dwelling to be expanded to permanent housing standard, otherwise there is a risk that it will be downgraded to other usage or abandoned. Also, it was found that relocation far outside city limits is possible in the case of middle class habitat providing that there are main arteries connecting with city centre, and in the case of lower class habitat providing there are job opportunities nearby.

It is important to look at different aspects concerning the container such as availability, energy consumption and cost implication. World Bank record indicates that there are more than 570 million of TEUs (twenty feet equivalent unit) containers being transported around the world in Year 2011 (World Bank 2013). For costal...
countries e.g. Malaysia, the flow of container has risen from 5 million to 11 million TEUs from Year 2005 to Year 2014, and each year there are as an average 43,000 TEUs containers left in Malaysia (Port Klang 2015). Same scenario in United Kingdom, where in Year 2002 there was a surplus of 125,000 TEUs containers left in the ports (Smith 2006). These left-over containers can be recycled into raw steel material or reused for non-transportation purposes i.e. shelters. Melting down a 3.6 ton (8000 lbs) container to make steel beams requires 8000 kW-hrs of electrical energy, but to convert it into a container shelter would require 400 kW-hrs energy, a saving of 95% energy (Container Home 2009; Vijayalaxmi 2010). This shows that reusing shipping containers for building architecture stands a chance to be an important solution to minimize carbon footprint and maximize shelter availability at the same time.

A comparison of embodied energy and indoor thermal performance of a container house to a conventional brick building has been made in India (hot and humid tropical climate). The results showed that fabricating the steel container needed 32317 MJ less energy than building a traditional Indian brick house and that the indoor temperature difference was only 0.3°C between the two types of structure. (Vijayalaxmi 2010). As the used container is a market commodity the price fluctuates, usually within the price range of USD 1000-1500 for a 20ft ISO shipping container. This gives a net area cost of 73-109 USD/sqm, compared to the average costs of transitional shelters of 139 USD/sqm and permanent dwellings of 166-388 USD/sqm in Haiti (Davies 2012), or to a safe building structure (foundation, columns, and roof) or to a small, safe house of USD 2,500-3,500 in the Philippines (World Bank 2014).

In the case of the South Asian tsunami 2004 the total needs for long-term recovery was estimated to USD13’700 million, and funds received from donor sources were about USD12’700 million. And in the case of the Haiti earthquake 2010 the needs were estimated to USD11’500 million and within seventy-five days United Nations and international partners pledged USD5’300 million, excluding funds made available from parallel and private sources. The increased risk of embezzlement and corruption should be remembered when injecting large amounts of reconstruction resources into partly dysfunctional poor economies and involving local governments. (TI 2008).

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Fig. 21. Integration between different parties in Post-Disaster Reconstruction

(Sandberg H. EPFL 2015)
Similar to other construction materials, the modified container core-dwelling offers many advantages as well as some unavoidable limitations. The positive aspects of using the container as post-disaster core dwelling are resistance to natural disasters, finalized structural module, easy availability world-wide, reusability, and minimal modification requirements applying skills and tools available in local ports and metal workshops. Unexposed steel structure can get very hot during the day due to direct solar radiation, and cold during the night due to direct thermal conductivity with the environment. However, the container core-dwelling will be embedded within the residential structure and thus protected against extreme thermal exposure. Design can further improve the ventilation and thermal insulation of the container core-dwelling to satisfy the local climate requirements in different parts of the world.

When converting a shipping ISO container into a core dwelling within a progressive-housing concept, questions may be raised from different parties that are involved in the post-disaster reconstruction process, such as shown in figure 21. The problem statements can be categorized into three areas:

i. Architecture

ii. Engineering / manufacturing

iii. Social Science / Aid Organization / Economics

Each problem statement area has been detailed out in figure 22. The originality and strength of the research is to have started collaborations and selected local teams that are more adequate (both culturally and scientifically) to study the social, cultural and economic aspects of feasibility and implementability of the solutions. A multidisciplinary approach is implemented. The motivation of each team is sharing its scientific knowledge, knowhow and cultural specificities in order to find original solutions, for the benefit of all.

Fig. 22. Architecture, engineering and social science problem statements
The chosen methodology (cf. Section 2) has taken ad nota past bad experiences and as indicated applies an interdisciplinary polylog interaction with an evolution/feed-back system. When a full-scale re-/construction project would start, the same approach is recommended to be used, of course. Then the focus would be primarily on the phases Implementability ⇔ Adoptability ⇔ Acceptability. And the process is of importance each time as it is not possible to freely extrapolate experience from one area/region to another. It is recommendable to have gender-mixed local project teams, in order to achieve an optimal contact with the end-users and an over-all information flow. After an initial introduction of the re-/construction concept to the end-users, the best approach is to be orientated towards passively providing advice and information and not towards actively enforcing solutions. However, within this framework active advice of security improvement in construction is important. The assistance can be made through local information centres set up in the re-/construction area, where the end-users can come and get advice, and when so decided sign out building supplies.

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