Time-Efficient Post-Disaster Housing Reconstruction with Prefabricated Modular Structures

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TIME-EFFICIENT POST-DISASTER HOUSING RECONSTRUCTION WITH PREFABRICATED MODULAR STRUCTURES

Tharaka Gunawardena, Tuan Ngo, Priyan Mendis, Lu Aye, Robert Crawford

Abstract

With many natural disasters such as earthquakes, cyclones, bushfires and tsunamis destroying human habitats around the world, post-disaster housing reconstruction has become a critical topic. The current practice of post-disaster reconstruction consists of various approaches that carry affected homeowners from temporary shelters to permanent housing. While temporary shelters may be provided within a matter of days as immediate disaster relief, permanent housing can take years to complete. However, time is critical, as affected communities will need to restore their livelihoods as soon as possible. Prefabricated modular construction has the potential to drastically improve the time taken to provide permanent housing. Due to this time-efficiency, which is an inherent characteristic of modular construction, it can be a desirable strategy for post-disaster housing reconstruction. This paper discusses how prefabricated modular structures can provide a more time-efficient solution by analysing several present-day examples taken from published post-disaster housing reconstruction processes that have been carried out in different parts of the world. It also evaluates how other features of modular construction, such as ease of decommissioning and reusability, can add value to post-disaster reconstruction processes and organisations that contribute to the planning, design and construction stages of the reconstruction process. The suitability of modular construction will also be discussed in the context of the guidelines and best practice guides for post-disaster housing reconstruction published by international organisations. Through this analysis and discussion, it is concluded that prefabricated modular structures are a highly desirable time-efficient solution to post-disaster housing reconstruction.

Keywords: *Post-Disaster Housing Reconstruction, Prefabricated Modular Structures, Natural Disasters, Time-Efficient Construction.*

INTRODUCTION

Providing permanent housing to disaster victims is one of the most critical and time-consuming activities in the post-disaster reconstruction process. As shown in figures 1 and 2 the Federal Emergency Management Agency (FEMA), the Florida Department of Community Affairs and the Florida Division of Emergency Management predict that permanent housing may take up to five years to realise from the time of the disaster's impact. For an average citizen, this is a very long time period to wait to restore their normal livelihood. As many experts term it, a 'new normal' is therefore set in many circumstances rather than providing exactly what existed previously.

Long-term solutions such as permanent housing are as important as the emergency relief provided after a major natural disaster. Prefabricated modular structures can provide a holistic approach to permanent housing reconstruction in disaster-struck areas. As analysed in this paper, many of the common issues that have arisen in previous post-disaster permanent housing reconstruction programmes can be provided with highly time-efficient and holistic solutions through modular construction.

The many inherent characteristics of modular structures, as listed below, allow for a speedy construction as well as a solution that is friendlier to the end user. Some of the relevant characteristics of modular structures are as follows:-

- All components of a building, including stairs, lift shafts, façades, corridors and services can be incorporated in such modules.
- The modules are mass produced in a quality controlled production facility ensuring greater quality control as well as more beneficial economies of scale.
- A module's shape and size can vary to suit a desired architectural plan, where the dimensions may only be limited according to the transportation arrangements such as truck dimensions and height restrictions on roads that need to be travelled on during transport of the modules.

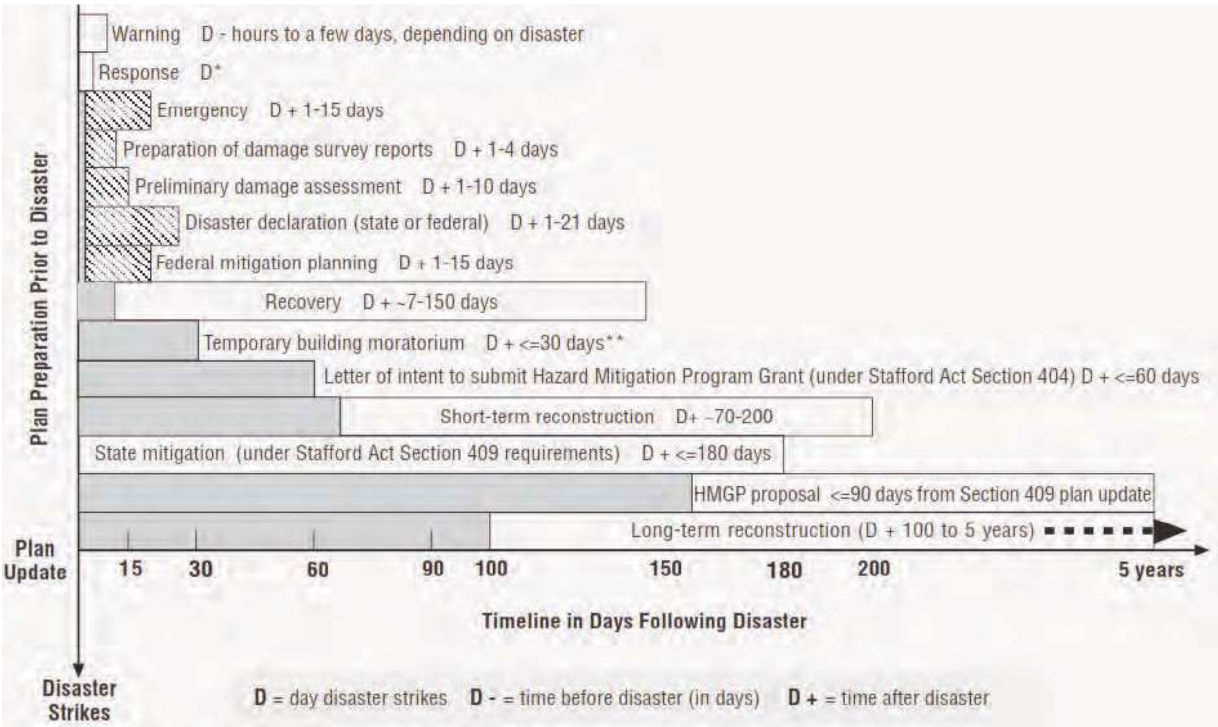

Figure 1. Post-disaster recovery and reconstruction timetable (FEMA, 2005).

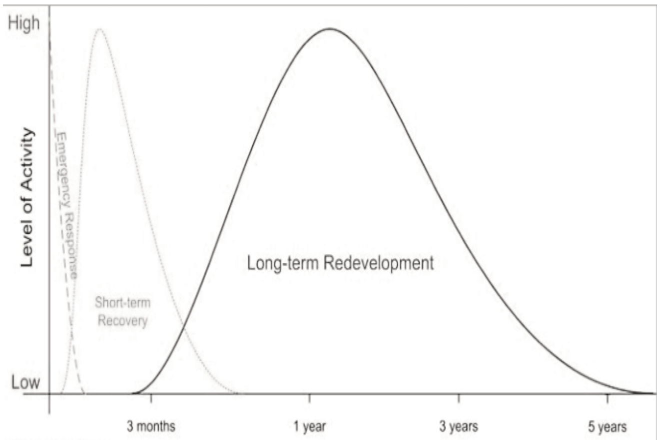

Figure 2. Probable post-disaster phased activity for a major disaster scenario (Florida Department of Community Affairs and Florida Division of Emergency Management, 2010).

- There is minimal work on-site to complete the buildings as the façade and interiors themselves form parts of the modules.
- The modules can easily be removed from the main structure for future reuse or relocation. Many developed economies now have a market for used modular units.
- Modular construction at present reduces construction time by over 50% from a site-intensive building (Lawson et al, 2012).
- Reduced construction time means that the modular houses become habitable for the end users much sooner than it would after the completion of a conventional construction.

In addition to the above mentioned characteristics, Rogan et al (2000) assess the costs and benefits of modular construction as against traditional construction, for a typical four-storey residential building in London. Where the initial investments have only been a mere 2 per cent higher for modular construction, it has shown to reap far greater benefits than the traditional construction approach, from the beginning of the usable life of the structure. With a 39 per cent greater turnover estimated and a 43 per cent higher Internal Rate of Return (IRR), modular construction was clearly shown to provide more benefits to the builder as well as the client.

This paper thus evaluates how these features of prefabricated modular structures can be used to provide a holistic and speedy solution to post-disaster housing reconstruction issues commonly raised by many of the major disasters that have occurred around the world.

PREFABRICATED MODULAR HOUSES IN REAL WORLD APPLICATIONS

Although the concept of prefabricated modules is only beginning to gain popularity worldwide, quite a few such buildings have already been built and inhabited in many developed countries. Almost all of these buildings are residential, and there is an increasing demand for this construction technique mainly due to the speed at which the final products are realised.

Prior to applying the technology to post-disaster applications, it must be observed how the concept is applied in real world applications. A few examples from around the world are described briefly to observe how prefabricated modular construction has become established as a practical commercial building methodology.

Little Hero building, Melbourne, Australia

The low-rise apartment building 'Little Hero' in Melbourne, Australia consists of 58 single-storey apartment modules and 5 double-storey apartment modules (see figure 3). The authors were part of the development team for this project. The eight modular stories were assembled with finishes within eight days, and the building was constructed at a site with a very narrow access road, thereby demonstrating some of the many advantages of modular construction.

Domino Housing 21, Spain

This is a four-storey structure built in Spain, where modules can be added or dismantled as the client pleases. The time taken to set up the full structure once planned is just 15 days. The building speaks volumes for the speed of construction that modular concepts provide, as the units can be added with additional boxes to add spaces and customise the existing ones even further.

Student housing building, Wolverhampton, UK

This 25 storey structure is claimed to have been completed in just 27 weeks of work on-site (see figure 4). Lawson et al (2012) explains this as a 50 per cent saving from the on-site time estimated for a site-intensive construction; they have estimated the productivity in terms of savings in man-hours as an 80 per cent improvement from a site-intensive construction. In general, Lawson et al (2012) state that modular construction can reduce site wastage up to 70 per cent compared to site-intensive construction methods.

Therefore, not only have modular structures proven time-efficient, but they have also proven to be more environmentally friendly, providing energy-efficient solutions. As discussed by Lawson et al (2012) in general prefabricated modular buildings have proven to reduce construction waste considerably and this is mainly through means of minimised off-cuts (Osmani et al, 2006). This in turn will result in significantly improved efficiency in energy, cost and time of construction.

Figure 3-1. Little Hero Building (modular building in Melbourne, Australia).

Figure 3-2. *Little Hero Building (modular building in Melbourne, Australia).*

Figure 4. *25-storey student housing building in Wolverhampton, UK (source: Lawson et al, 2012).*

Post-Katrina housing, Mississippi, USA

Due to the large housing demand which followed the Hurricane Katrina disaster in 2005, much research has gone into improving the previously used 'FEMA Trailers' and to implement modular construction for temporary housing. A design by Architect. Marianne Cusato inspired this modular house, which was named the 'Katrina Cottage' (see figure 5). It was designed to be installed with a floor area of 27.8 square metres. However this was improved to incorporate a more permanent housing solution with 20 different cottage models that allowed for future extensions (McIntosh, 2013).

Haiti post-earthquake reconstruction - temporary housing

Following the Haiti earthquake in 2010, the Canadian Embassy in Haiti carried out the installation of 46 modular housing units as temporary shelter for 75 individuals (see figure 6).

INTERNATIONAL GUIDELINES ON POST-DISASTER HOUSING RECONSTRUCTION

FEMA (2005) and Oxfam (2003) define the terms 'Shelter' and 'Housing' with respect to post-disaster relief operations. Both institutions identify shelter as temporary dwellings, provided until such time that the affected people could be moved into more permanent houses. Shelters are meant to be only a temporary safety net for the displaced to protect against diseases, health issues and further disasters.

In a more non-traditional context, Shelter Project. org (2003) defines a shelter as a "*Habitable covered living space, providing a secure, healthy living environment with privacy and dignity to those within it.*"

'Housing' on the other hand is identified as permanent dwellings, which are associated with necessities in the form of physical, social and administrative infrastructure. This in turn reflects the need of permanent housing to cater to the livelihoods of the disaster-affected communities in the long run.

Many agencies such as Oxfam (2003), APEC (2009) and UNDRO (1979) have identified that the transfer of technical know-how to the parties involved in a disaster relief operation can slow down or affect the process adversely. It is understood that most disaster relief operations include the help from many non-technical parties such as locals including the disaster victims themselves. As most of them may not be experts in construction technology, the knowledge gap will affect a mass housing construction operation in a very adverse manner.

As many locals show a great deal of enthusiasm during the post-disaster housing process, Oxfam (2003) suggests the following 'pre-emptive strategies' to handle the inputs:

- "Matching technology to capacity" – This

Figure 5. The original 'Katrina Cottage' (source: McIntosh, 2013).

Figure 6. Modular housing units installed by the Canadian Embassy in Haiti (source: Sullivan Land Services, 2010).

involves an initial study on the individuals that are involved in the process, and the time commitments, expertise and skills that can be expected from them.

• "Project schedules should be realistically based" - This is to ensure that the housing process makes effective use of the parties involved and their expertise and skills.

• "Building model houses" – This will provide a

Disaster	Source	Countries Affected	Magnitude	Damage Caused
Kocaeli Earthquake (1999)	Tas et al. (2011)	Turkey	Magnitude 7.4	– Approx. 17,000 casualties – 120,000 houses damaged beyond repair – 50,000 houses heavily damaged – 2,000 buildings collapsed – 300,000 people displaced
Indian Ocean Tsunami (2004)	Weerakoon et al. (2007)	Indonesia, Sri Lanka, India (Case study focus on Sri Lanka)	Magnitude 9.5 earthquake followed by Tsunami	– Approx. 36,000 casualties – 800,000 people displaced – 89,000 houses destroyed
Kashmir Earthquake in Pakistan (2005)	Arshad & Athar (2013)	Pakistan, India (Case study focus on Pakistan)	Magnitude 7.6	– Approx. 100,000 casualties – 3.5 million people displaced
Japan Tsunami (2011)	Structural Engineers Association, Washington (2011)	Japan	Magnitude 9.0 earthquake followed by Tsunami	– Approx. 16,000 confirmed casualties – More than 300,000 displaced – Over 100,000 houses destroyed

Table 1. Background details of the natural disasters of the analysed case studies.

better understanding to the planners as well as everyone involved as to how the full process will pan out. All involved parties can identify what they can expect in the real process.

Oxfam (2003) further identifies the importance of the technological know-how in dealing with construction materials.

In addition to the construction-related issues discussed here, HIC-HLRN and PDHRE (2005) have identified human rights related concerns that need to be addressed in a post-disaster housing process. It strongly suggests that no resettlement programme should be undertaken without considering internationally recognised human rights being in place. In general, it strongly states that the livelihoods of affected individuals should be reinstated as soon as possible to ensure that their natural development is not hindered or damaged beyond repair.

POST-DISASTER HOUSING RECONSTRUCTION IN THE PAST

Post-disaster recovery processes for many of the recent disasters have been recorded by the parties involved and it is worthwhile to examine them. This gives an understanding as to which key problems have occurred more commonly and which may need an innovative solution. The post-disaster reconstruction processes of the following disasters are studied here as case studies:

- Housing reconstruction in Turkey following the Kocaeli Earthquake in 1999.
- Housing reconstructions in Sri Lanka, India and Indonesia following the 2004 Indian Ocean Tsunami.
- Housing reconstruction in Pakistan following the Kashmir Earthquake in 2005.
- Housing reconstruction in Japan following the 2011 Tsunami.

Table 1 shows a summary of the background data of these natural disasters and Table 2 is a summary of the housing reconstruction undertaken. This is a depiction of the magnitude of damage that natural disasters of this nature can cause, and how long it can take to permanently restore the livelihoods of those affected.

Studies carried out on the post-disaster housing reconstruction of the above mentioned cases are analysed to identify how a modular construction can solve many of the commonly faced issues as identified through these examples.

KEY ISSUES IN THE RECONSTRUCTION PROCESS AND SOLUTIONS OFFERED BY MODULAR HOUSING

Although different in magnitude and nature, the disasters studied in this paper have provided a set of common issues to the process of reconstructing houses. It is useful to therefore identify some of these key issues and then assess how a smart solution can be provided through modular construction. Explained below is how these issues were identified by many researchers who analysed these post-disaster processes.

Time

People displaced due to natural disasters need assistance in restoring their original livelihoods.

Disaster	Source	No. of Houses Reconstructed	Value of Housing Reconstruction	Completion of Housing process
Kocaeli Earthquake, Turkey	Tas et al. (2011)	43,093	$5 billion (estimated)	Over 6 years
Indian Ocean Tsunami in Sri Lanka	Weerakoon et al. (2007)	Approx. 60,000	$ 700 million	3-5 years
Kashmir Earthquake in Pakistan	Arshad & Athar (2013)	463,000	$ 1.5 billion (estimated)	Approx. 5 years
Japan Tsunami	Structural Engineers Association, Washington (2011)	-	-	Still continuing 2.5 years after disaster

Table 2. *Reconstruction data summary for the natural disasters of the analysed case studies.*

Therefore time is a critical factor, as restoring their lives needs to be done as early as possible. Tas et al (2010) have identified 'time' to have a significantly higher rank over the other factors that determine the design of post-disaster permanent housing (see figure 7).

In the above mentioned case studies, the finished housing projects have taken at least five years to complete. This is a considerably long time for disaster-struck communities to wait to rebuild their lives. Weerakoon et al (2007) identified how factors such as inflation and foreign exchange rate fluctuations have drastically increased the price of construction materials over a lengthy stretch of time (see figure 4) and the changes in wages for labour over time (see figure 5), which made the reconstruction process in Sri Lanka costlier than it should have been.

Time efficiency of modular construction is one of the key features that make it a highly desired new technology. As Lawson et al. (2012) claims, modular buildings can reduce construction time by

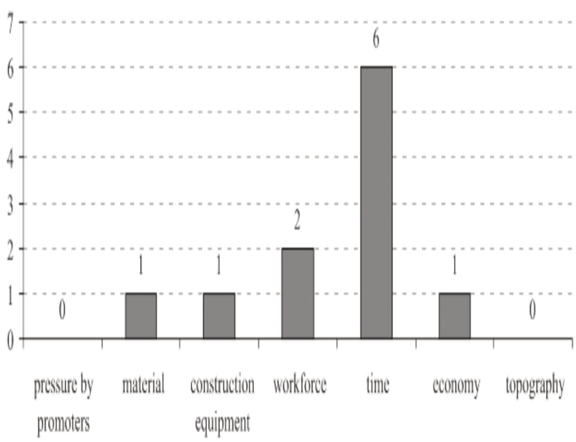

Figure 7. *Ranking of the determining/restricting factors in permanent housing design – with respect to the Kocaeli-Turkey earthquake in 1999 (source: Tas et al, 2010).*

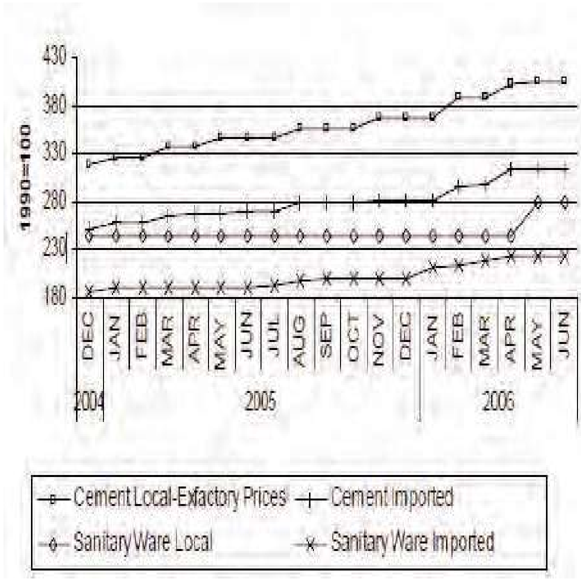

Figure 8. *Price changes through time of imported and local construction materials (source: Weerakoon et al, 2007).*

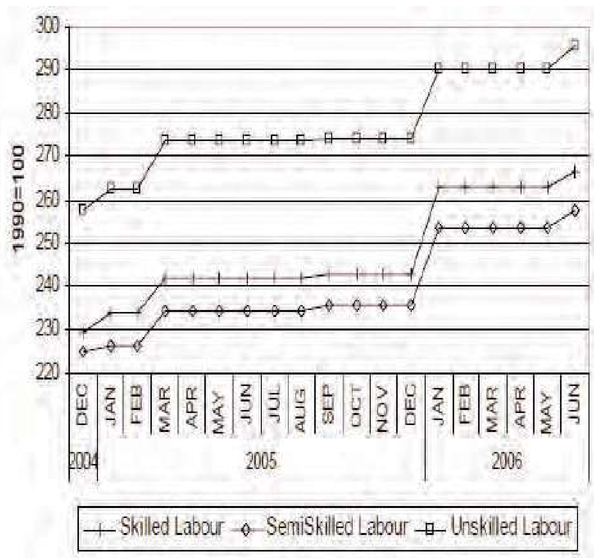

Figure 9. *Changes through time in wages for labour (source: Weerakoon et al, 2007).*

almost 50% compared to more conventional site-intensive constructions.

Many houses can be simultaneously built through mass production facilities and also simultaneously installed on-site, which will cut down construction time. This time saving means that the affected communities can recommence their livelihoods much sooner. Further, the funding for the project will also make greater savings by avoiding time fluctuations in material and labour costs and exchange rates.

Resource availability and integration

Yan et al (2010) have categorised resources as "*Government-driven, Market-driven and Donor-driven*" prior to identifying the related issues. They have identified that although government-driven operations have an initial advantage of price and rate interventions from the government, eventually they succumb to economic factors such as inflation of material prices and rises in wages. Donor-driven processes have shown a lack of capacity in having resources available. Market-driven processes are seen as the most desirable in terms of performance and results, but they lack support from the stakeholders such as governments and humanitarian agencies.

In a later study, Yan et al (2011) identified five main types of factors that affect resource availability in post-disaster reconstruction, namely:

- Market- related factors
- Logistics-related factors
- Project-related factors
- Organisation-related factors
- Environment-related factors

Tas et al (2011) have reported that almost 16 different contractors were involved in the reconstruction process after the Kocaeli earthquake in Turkey. This is a large number of different firms working on the same project, which would eventually require a good platform of integration.

Although modular construction as a technology may not solve the resource availability issue, it has the potential to considerably reduce the burden of finding resources. Many logistics-related factors as stated by Yan et al (2011) can be reduced by having almost all of the operations running under one manufacturing plant; whereas in a site-intensive construction different resources would need to be called upon at different times by different contractors.

Arshad and Athar (2013) in their study on the rehabilitation after the Kashmir earthquake have pointed out that engaging a limited number of parties in the reconstruction process is a key success factor. Modular construction by its character involves a minimum number of parties, as the house is already built by the time it arrives on site. Most of its construction is done as pre-organised mass production, which is streamlined and will mostly not be affected by the nature of the situation. Most processes are already integrated before modular units are assembled on site. Modern integration techniques, such as Building Integration Modelling (BIM), can also be applied easily to support the design and planning process of modular construction.

Further, Rogan et al (2000) have stated that the 'lead-in time' from ordering to delivery can be cut down to as low as 6 to 8 weeks if the products have been prototyped previously through projects of similar nature. This may vary with the location in consideration and how far away it is from a production facility. It is advisable therefore, for a disaster management organisation to have typical designs for several types of modules to suit different post-disaster conditions. Since these module types will be predesigned and pre-engineered it will improve the planning and lead-in times considerably. However, this suggests that if the parties involved in disaster relief operations can plan early and be prepared, ideally before disaster strikes, they will benefit tremendously with modular construction.

Considering the large amount of houses often required following a natural disaster, suppliers will need to possess capability to deliver large number of modules at short notice. However, modular construction would still be the best equipped to cater to this large demand as economies of scale will largely benefit modular construction as opposed to traditional means (Rogan et al 2000).

Availability and skills of workforce

As observed from the data in Tables 1 and 2, the number of houses that need rebuilding after a large-scale natural disaster can be extremely large. This requires an appreciably large workforce, which may be unrealistic to be found at once. Arshad & Athar (2013) acknowledge that lack of knowledge and/or skills of the locals assisting was a key issue during the reconstruction process in Pakistan after the 2005 Earthquake.

The expertise for the construction of a modular housing unit is mostly needed inside the manufacturing facility. Once the modules arrive on site, they will only require a minimum amount of labour for the installation process. As mentioned previously, it is observed that local communities volunteer during many housing reconstruction processes, and the expertise needed in the on-site construction of modular houses is minimal where they can provide a better and more efficient service. The activity needed on-site can be as minimal as tightening a few nuts and bolts, and local volunteers with minimum work experience could be trained easily to carry out these tasks.

Lack of expertise in planning

As previously mentioned, publications such as Oxfam (2003) and Roosli et al (2012) identified a lack of expertise and knowledge in the relevant authorities about the process of housing reconstruction acting as a major setback in the housing reconstruction process. They also identified the importance of all approaches and plans being integrated as a universal plan, which is lacking in many large-scale post-disaster housing operations.

A high percentage of the construction process of a modular structure is a pre-planned process carried out in a factory environment. The process to construct a module from its raw materials should not require any drastic changes even during a post-disaster reconstruction scenario.

External parties would only get involved in the on-site construction and for integrating the infrastructure. Modular units are generally built with provisions for services. It is only a matter of connecting them on-site once the modules are assembled. Further, since the interiors as well as façades, roofs, etc. are all pre-constructed into the modules, the planning required becomes much simpler. This provides a more workable platform for institutions of various disciplines, such as contractors, governmental institutions, non-governmental organisations and humanitarian agencies, to work together and produce better results.

Overall quality of houses and end user satisfaction

Eventually, the satisfaction of the end users is a key concern. Although the affected individuals may eventually be thankful for the resettlement of their livelihoods after possibly losing all their possessions, it must be understood that they are entitled to be opinionated of the quality of the finished product. For this reason institutions such as FEMA, APEC and UNDRO have set standards for post-disaster housing reconstruction.

SEAW (2011) with respect to post-disaster operations in Japan, suggests that having timely solutions to housing will reduce the burden on social services, and the stress on affected individuals by living in temporary shelters. To satisfy this requirement fully, the housing solutions will need to cater to most of the requirements of those individuals, which will then reduce their grievances by having minimal defects and desires not fulfilled.

The production of a housing module is done in a highly quality controlled environment. The quality checks inside a mass production facility will be more reliable compared to an on-site construction, especially in a post-disaster scenario where on-site construction will be under heavy pressure for delivery.

Further, modules can be adjusted to suit the needs of the end users, and as the construction is highly time efficient, the parties involved can take time to analyse the situation and to plan for the specific requirements of the affected community. This will make sure that the final product suits them with respect to both structural stability and liveability.

Other benefits

Modular construction requires minimum access roads as on-site construction will be minimal. Modular units can be shipped in or transported on trucks and placed on site using mobile cranes. This is a very convenient and practical method of construction, especially in a disaster struck area where vehicle access could be a key limiting factor.

Modular structures have proven to be more environmentally friendly than conventional steel or concrete buildings. Far less waste is generated by modular construction, thereby giving it an edge in having a smaller impact on the environment, which may result in time and cost savings over reduced expenses in dealing with waste. In further studies, Aye et al (2012) have found that more than 80% of the embodied energy in an original steel modular system can be saved by reusing the modules. It is important to notice the advantage provided by modular units by its ability to be easily dismantled and relocated as and when the need arises. This can provide a great deal of flexibility in a post-disaster housing operation.

Modules can also be easily dismantled for relocation. If the tenants are unhappy with where they are located the relevant agencies can help them relocate with the houses they have been provided with. This adds value to the operation by being more oriented towards the human needs as suggested through HIC-HLRN and PDHRE human rights requirements.

CONCLUSION

It is observed from the different examples from around the world that permanent housing can take years to realise after a disaster, while temporary housing could be provided in a matter of days. Modular construction can drastically improve this time gap. The faster construction times, which are characteristic of modular construction, make this form of construction a great solution for providing faster permanent houses.

Factors such as scarcity of resources, deficiencies in transportation, funding, etc. can still have a detrimental effect on the efficiency of a modular construction. However such factors can be expected in a post-disaster scenario. Modular construction can provide a more integrated approach where economies of scale that arise through mass production will provide a valuable solution to funding difficulties. As almost all the building components would be integrated into one single module before it leaves the manufacturing plant, the disaster relief operation would depend on a single contractor instead of various different contractors and subcontractors. This characteristic of modular construction will simplify the entire process of post-disaster housing.

A great advantage of using modular structures as a post-disaster housing solution is that much of the expertise in reconstruction is directed to one solution provider. As seen in many cases studied in this paper, the expertise of appointed officers and institutions on the technologies involved is a key factor related to the speed of providing housing solutions.

The higher quality standards that can be assured due to the modules being constructed under a quality controlled environment such as a manufacturing plant will ensure greater satisfaction to the end users. Modules can be pre-engineered to perform at various climatic conditions in order to provide a better indoor climate to the dwellers. Better preparedness and having a set of modules that were prototyped previously with well-established production logistics, can result in even faster delivery of final products. Techniques such as BIM can be used to efficiently gather and channel all such design requirements from a disaster struck community to the designers, and modular construction will be highly compatible to associate such requirements to produce custom-designed houses in a much faster time period. This is a great way to ensure that the livelihoods of the affected communities are restored to their satisfaction, and to ensure that their basic human rights on permanent housing are provided as early as possible.

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Author(s):

Tharaka Gunawardena *(corresponding author)*
Department of Infrastructure Engineering
The University of Melbourne
Email: tharakag@student.unimelb.edu.au

Tuan Ngo
Department of Infrastructure Engineering
The University of Melbourne

Priyan Mendis
Department of Infrastructure Engineering
The University of Melbourne

Lu Aye
Department of Infrastructure Engineering
The University of Melbourne

Robert Crawford
Faculty of Architecture, Building and Planning
The University of Melbourne