

Sustainable organic building materials for housing: the case of post-disaster reconstruction in Indonesia

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ABSTRACT: Housing reconstruction in Aceh after the 2004 Tsunami typically followed the ubiquitous 'bungalow' model constructed from industrial products such as brick and concrete. The adoption of such materials extended the trend away from the use of organic building materials of traditional housing. On the other hand, after the 2006 Yogyakarta Earthquake, many aid agencies built transitional housing with bamboo—well-built, incorporating risk reduction elements and with comfortable indoor living conditions. Three years later these houses continue to be used, even by households provided with permanent housing. These examples suggest that in the housing sector in Indonesia adequate effort has not been invested in upgrading and improving building traditions using organic materials suitable for the climate, testified by traditional architecture using less energy in its production and use, using renewable building materials and thermally comfortable. A Life Cycle Assessment comparing a traditional Acehese house with a sample of typical reconstruction houses reveals that its greenhouse gas emissions impact is significantly much less—in that sense representing a sustainable housing typology. Thus this paper advocates the promotion of organic building materials within a sustainable management policy framework by prioritising sustainability over issues of perceived convenience and economy.

Conference theme: Global

Keywords: Organic building materials; Housing reconstruction; Sustainability; Life-cycle assessment.

INTRODUCTION

Housing in the hot-humid regions of Southeast Asia was traditionally constructed from organic building materials including timber, bamboo and thatched grasses. This was once a sustainable system refined over many generations to form identifiable housing systems closely connected to cultural expressions. In Banda Aceh, the capital city of the Daerah Istimewa Aceh (Special Region of Aceh), the traditional type of Acehese house is being re-imagined as a masonry 'bungalow' styled house.

As with many other parts of Southeast Asia the decline in popularity of the traditional timber house is in part blamed on the effects of deforestation and the associated high cost of timber (Oliver 1997, Chaichongrak *et al* 2002). High timber prices are linked to deforestation, industrialisation, overpopulation and corruption (Dauvergne 1997, Global Witness 2002, FAO 2001). Within the Aceh region quality timber is now expensive and is commonly only available in shorter lengths than those required by custom (Nas 2003).

The new aspirations of inhabitants have also led to the adoption of new housing forms. As in other parts of Southeast Asia, access to television introduced new living patterns and aspirations closely connected to consumerism, new lifestyles and new forms of housing (Hamilton 1992, Askew 2002, Ockey 1999). Aceh has also identified with the international cultural flows – identified by theorists such as King (1991) – that 'globalise' architectural space, form and materials. Hence the house has become one of the many universal artefacts of the present era and is a place where the shared 'human condition' is expressed. Nas (2003) argues that in Banda Aceh the primary motivations that lead to contemporary bungalow housing types include diminished access to suitable timber supplies, the notion that the traditional house is less practical than its contemporary alternative coupled with perhaps the most pervasive idea that people are expressing an "interest in change and wish to keep up with the times" (Nas 2003: 133). "Modernization and the availability of modern building materials such as brick and concrete stimulate people to alter their immediate living environment" (Nas 2003: 134).

As these changes flow through communities, such as in Indonesia, the most obvious choice has been to use brick and concrete technologies. New houses inevitably come complete with the styles and spatial planning common in urban areas and feed into desires to express socio-economic advancement. However it is apparent that a raft of problems accompanies this shift and that the new techniques are unsustainable – economically, socially, culturally and environmentally.

1. POST-DISASTER HOUSING RECONSTRUCTION IN INDONESIA

1.1. Aceh

The 2004 Indian Ocean Tsunami dramatically exacerbated the changes to Indonesian housing culture in Aceh. The widespread destruction of houses led to a massive relief effort and dozens of international and local aid agencies participated in one of the most comprehensive reconstruction programs ever mounted. Reconstruction agencies working in Aceh readily adopted the bungalow type and its derivatives and have built with reinforced concrete, masonry (concrete block and brick), steel framing, and corrugated iron sheets. However there has been little research evaluating the environmental sustainability of this approach. Literature on the reconstruction process in Aceh falls into two main categories. Firstly there are the reports produced by the agencies involved in reconstruction. These reports follow a similar format and detail the difficulties faced, the responses taken and future projects. Secondly, independent critiques of the reconstruction work are more likely to concern issues such as inequity, corruption, inappropriate aid allocation, delayed reconstruction, lack of planning and inadequate construction quality (see for example Boen 2006, Eye on Aceh 2006, Forbes 2006a, Forbes 2006b, Perlez 2006, Steinberg 2007, Tsunami Evaluation Coalition 2006). However none of this literature questions the strategy to focus the reconstruction effort on any other housing type other than the bungalow type – neither is there any in-depth analysis of the sustainability issues that arise. An exceptional study in this regard is by Roseberry (2008), which examines the sustainability issue and identifies that the construction materials used in reconstruction are associated with high levels of embodied energy and embodied CO₂; however a close comparison between specific house types has not been undertaken.

Moving forward with the industrialised 'bungalow' model, particularly at the initial phase of reconstruction, can be attributed to the pressure to produce vast numbers of houses in a short time frame and this was an easy model to adopt compared to deriving ideas based on local building traditions. In the face of government pressure, aid donors and implementing NGOs, and to some extent even the communities devastated by the tsunami, were often forced to focus on obtaining quick results and there was little scope for a full analysis of the economic and environmental sustainability of the concrete and masonry houses and the long-term effect they might have on the social and cultural sustainability of the affected communities. The high financial cost of items such as cement, steel reinforcing and strengthened masonry walls – considered as necessary to reduce future disaster risk – were deemed acceptable while the inherent capacity of more affordable lightweight organic construction materials to resist hazards (Boen 2006, Dall 1982) was largely overlooked.

1.2. Yogyakarta

A less widely publicised disaster was the 2006 Earthquake in Yogyakarta that resulted in nearly 6,000 fatalities and rendered more than 1 million people homeless. More than a year after the tsunami, some of the aid agencies working in Aceh seemed to have gained some lessons and applied them in Yogyakarta. Here agencies supported the community-based self-help construction of nearly 2,500 sturdy transitional shelters for people displaced by the earthquake, using bamboo as the principal material. The bamboo frame of the shelters incorporated cross-bracings and struts to resist lateral stress from seismic movement and special attention was given to securing the frame connections strongly with ropes, without using nails that split and weaken bamboo. In many cases, the bamboo was treated for increased longevity. Even though they were transitional, the shelters were built with a view toward seismic resistance.

Some of the benefits of such construction include:

- Anti-seismic as lightweight and tensile
- Simple: easy to train beneficiaries and relies on local resources
- Cost-effective
- Participative: allows beneficiaries to be involved in the construction process
- Contributes to local economy as resources are obtained, processed and produced locally
- Porous bamboo walls allow natural ventilation and create comfortable indoor living conditions.

In the face of possible uncertainty and delay in provision of permanent shelter, well-built transitional shelter allowed households to lead normal lives. While these houses were expected to serve as a short-term transitional solution before permanent brick and concrete houses were built, nearly three years later the houses continue to be used, even by households that have been provided permanent housing. These observations were made by the first author during a larger global study (Wilderspin *et al* 2008). The Yogyakarta experience indicates the potential for upgrading and improving traditional organic building materials to build good quality, contextually appropriate and sustainable housing instead of adopting industrial building products as the only solution.



Figure 1: Bamboo transitional shelter in Yogyakarta

2. LIFE CYCLE ASSESSMENT (LCA)

This paper analyses the issue of environmental sustainability by applying the Life Cycle Assessment (LCA) process and comparing the relationship between house type and environmental sustainability. It focuses on the relationship between construction technologies and environmental impacts. Four case-study houses in Aceh have been selected for this analysis. The first is an example of the traditional Acehnese timber house type built approximately thirty years ago. Houses 2, 3 and 4 were built by international aid agencies.

LCA is a technique for assessing the environmental aspects and potential impacts associated with a process – in this case the production, operation and end-of-life disposal of the four case-study houses. It calculates the effects that this process has on the environment over the entire period of its lifecycle. It does this through two steps. Firstly it requires an inventory of relevant inputs and outputs of a product system before evaluating the potential environmental impacts associated with those inputs and outputs (International Standards Organization 1998). Evaluation is made using *SimaPro* – a computer program developed by PRe Consultants in the Netherlands and incorporating a database provided by the Centre for Design at RMIT University, Australia. Although the *SimaPro* process incorporates a series of generalisations and assumptions it follows a transparent process that analyses each component of a system to produce numeric data, allowing comparison of systems. Scoping studies of this type are by their very nature speculative. However the intrinsic value of a process that models this type of data is its ability to detail a transparent process that enables systems to be compared and allows conclusions to be drawn. The generalisations and assumptions inherent within the program are carried across all four of the studied houses and so the inconsistencies of the system are generally equalised. Each of the four case-study houses was compared with values for each component entered into a database so that a series of comparisons could be made. An important measure of sustainability has been quantified and reported in this paper - the carbon footprint - a measure of the quantity of greenhouse gases emitted across the full life-cycle of the house, from the extraction of the raw materials used in construction through to the disposal of the materials at the end of the life of the house.

2.1. Analysis

To do the comparative testing some assumptions had to be made: firstly that all houses have a similar lifespan; that all have comparable electricity usage (generally this would include a single fluorescent light, small television and two electric fans); and finally that all will be recycled to a similar degree at the end of their lifespan with only 10% ending up either burnt or becoming landfill.

Each of the case-study houses has undergone an inventory analysis whereby all the construction components have been quantified. Quantities vary as the houses are different sizes and styles. Houses 2, 3 and 4 are built with similar set of basic materials albeit with different systems, while House 1 is built from an entirely different set.

Impact assessments identify links between a product's life cycle and its potential environmental impacts (including factors such as greenhouse effects and ozone depletion). This assessment does not include all impacts – for example, the environmental impact of the rice the builder eats – but does include the impact of energy used by mechanical construction equipment. Here the impact assessment relating to the indicators of Greenhouse Gas Emissions (measured in Greenhouse gas equivalents – CO₂eq) is presented; although other impacts such as the Ecological Footprint (that is, impact on land use) were also measured, the scope of this paper does not allow reporting them here. The Greenhouse impact model is based on the 'IPCC Recommended Greenhouse Emission Factor' developed for Kyoto protocol accounting and is based on a 100 year emissions timeframe. It must be noted that each of the case-study houses differ in size to a significant degree – the timber house is triple the size of the concrete house and more than double the size of the fibre-cement prototype. Consequently the comparisons have also been calculated on a per square metre basis.

2.2. House 1 – traditional Acehnese house

The traditional Acehnese house is well documented (Collier and Collier 1997, Dall 1982, Nas 2003) and the description here draws upon these accounts. The house is built almost entirely from organic building materials such as timber, bamboo and thatch. It is raised above the ground on timber posts that rest on flattened stone blocks. The elevated floor is made of bamboo slats and supported by a system of timber joists and bearers. Walls are made of

timber planks with decoratively carved skirting boards and panels. Upper wall components have latticed screens of bamboo or rattan that enable cross ventilation while doors and windows commonly have decorated wooden shutters. The thatch roof, usually made with palm fronds, is supported on a system of timber and bamboo battens, rafters and carved king posts. The house is held together with a series of crafted joints and no metal nails are required. The space under the house is utilised for various activities including relaxation, rearing of animals and storage. Overall the house has generous proportions and typically the upper floors cover 90m² with an additional 90m² of space below.



Figure 2: Traditional Acehnese house (source: Hugh O'Neill)

2.3. House 2 - Caritas

This house is one of three types built by Caritas International and closely follows the bungalow model. The load-bearing walls are from hollow concrete block and rest on reinforced concrete strip footings. Walls are strengthened with reinforced concrete posts and the floor is made from reinforced concrete. Interior partition walls are made from fibre-cement boards attached to a steel frame. Concrete block walls have been plastered with a sand/cement mix and painted. Door panels and frames are timber and window frames are aluminium with sliding glass panels. The gabled roof and gable ends are clad with corrugated iron sheet attached to a steel truss system. The house has two bedrooms and a living area, with kitchen and toilet at the rear. The total area of the house is 52m².



Figure 3: Caritas reconstruction house under construction (source: Ingvar Ando)

2.4. House 3 – Habitat for Humanity

House 3 was built by Habitat for Humanity and uses both local and imported construction techniques. The wall footings use local rubble stone and a thin reinforced concrete strip footing supports brick masonry walls. The masonry walls are reinforced at wall junctions with reinforced concrete posts and additional strength is provided from two reinforced concrete horizontal bands running continuously through the masonry walls. The masonry walls are finished with sand/cement plaster coat and are painted. Doors and windows are timber framed, doors have timber panels and the windows are glazed. Timber has been used for the walls of the kitchen and roof framing. The lower part of the kitchen walls are masonry with plywood panels above. The gabled roof is built from corrugated iron sheet cladding over a timber truss framework. The layout of the house follows a typical bungalow format as House 2 and includes two bedrooms, a living/dining room and kitchen and toilet at the rear. The house covers a total area of 56m².



Figure 4: Reconstruction house built by Habitat (source: Wing Roharjo)

2.5. House 4 – Uplink

Uplink houses were of two main types – one based on the bungalow format as described in Houses 2 and 3, the other raised above ground on stilts and relates to the traditional Acehese house typology. This type uses reinforced concrete columns in a grid, interconnecting with reinforced concrete beams supporting the floor. The enclosed living area is built on a reinforced concrete floor slab raised 2 metres above ground level. The walls of the enclosed living space are brick masonry to waist height with timber framed and clad walls above. The gabled roof of the house has corrugated iron sheet attached to a timber truss frame. All doors have timber panels and timber frames and windows are top-hung with glass panels and timber frames. The bathroom is the only enclosed space at ground level and has been constructed with brick walls and internal ceramic tile cladding. The remaining open area below the house offers scope for additional social activities and the storage of household goods in much the same way as the traditional Acehese houses. A timber staircase leads from the ground to the upper floor. Excluding the staircase this house covers 32m² on each level.



Figure 5: Reconstruction house built by Uplink

3. LCA RESULTS

Various aspects differentiate the four houses described above: types of materials, size, form and spatial layouts. The first phase of the research measures the quantities of construction materials used to build each house. An inventory analysis for each house has been undertaken through which every single construction component is quantified and recorded in cubic metres. The results are summarised below in Table 1.

Table 1: Summary of material quantities (m³)

Material	Traditional	Caritas	Habitat	Uplink
Reinforced concrete		5.832	5.010	10.622
Timber	15.345		2.191	2.415
Thatch	8.215			
Bamboo	1.313			
Plywood		0.100	0.653	1.832
Concrete block		10.000		
Brick			12.150	4.848
Stone	1.152		10.920	
Cement plaster		0.845	0.750	0.522
Fibre-cement		0.084		
Paint	0.010	0.015	0.015	0.010
Ceramic tile				0.016
Steel		0.233		
Corrugated iron		0.033	0.039	0.032
Gypboard				0.339
Aluminium		0.002		
Glass		0.047	0.015	0.022

3.1. Greenhouse gas emissions per house

Figure 6 compares the carbon dioxide (CO₂) greenhouse gas emissions (measured in kilograms) associated with the construction, running costs and end-of-life disposal of each of the four case-study houses as described earlier. It reveals that the traditional timber house has an exceptionally low greenhouse impact as compared with the reconstruction types that demonstrate significantly much higher greenhouse emissions. The Caritas house is nearly

forty times higher, the Habitat house nearly thirty times higher and the Uplink house emissions up to fifty times higher than the traditional house.

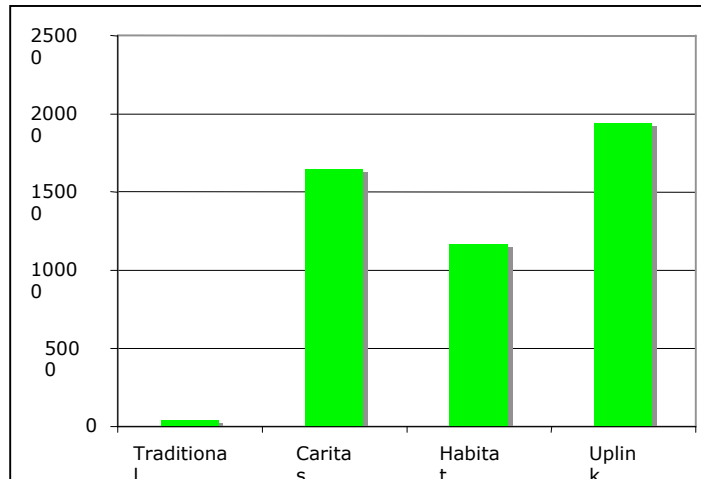


Figure 6: Greenhouse gas emissions per house (kg CO₂eq)

3.2. Greenhouse gas emissions per square metre

The disparity between the construction type and quantity of emissions becomes further emphasised when considered on a per square metre basis. At 32m² the Uplink house provides the smallest amount of enclosed space, nearly one-third of the 90m² traditional house. It would be most unlikely that the Uplink house, or for that matter the Caritas or Habitat examples, could house as many residents as the larger traditional house, which had evolved to typically accommodate large extended families. In the aftermath of any disaster, such as the tsunami, bigger houses become a more valuable asset as they have the capacity to support larger numbers of displaced residents. Hence house size, measured in square metres, must play an important role in any assessment of house type.

Figure 7 compares greenhouse gas emissions per square metre of enclosed space, that is, the spaces within a house enclosed with both roof and walls. Results show an increased disparity between the amounts of greenhouse gas emissions associated with traditional construction with organic materials as compared with contemporary construction techniques employing industrial products. Emissions associated with the traditional house are negligible as compared with each of the reconstruction houses. On a comparative basis the traditional house produces less than 1% of the emissions associated with the Uplink house, less than 1.5% of the Caritas house and less than 2.3% of the Habitat house.

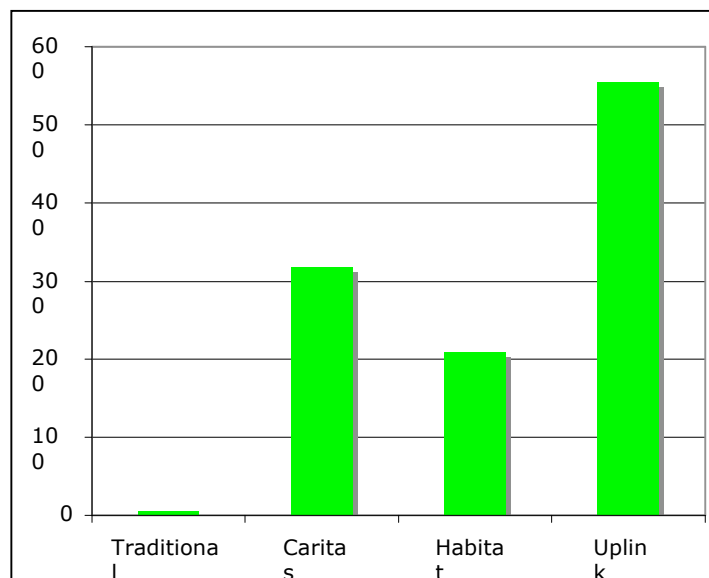


Figure 7: Greenhouse gas emissions per square metre (kg CO₂eq)

CONCLUSION

The above observations indicate that the widespread and increasing adoption of mass-produced industrial building materials has long-term implications of unsustainable impact on the environment, which is an ongoing process in most Southeast Asian countries. The post-tsunami context in Aceh where a large volume of housing reconstruction

was carried out within a short time span represents an intensified version of this impact, the repercussions of which are yet to be felt and understood fully.

It is necessary to derive lessons from the post-tsunami housing reconstruction process in Aceh, as done to some extent in Yogyakarta, to avoid similar pitfalls in future post-disaster reconstruction situations. Despite being increasingly undermined, there are still existing traditions of sustainable house construction with organic building materials in Indonesia and other Asian countries, and these can be drawn on as sources for progressing towards future sustainable solutions. Overlooking these traditions and supplanting them with construction and materials that prove convenient is an over-simplified approach to the problem. It shifts the focus from seeking ways to nurture these traditions and the need to formulate policy and practice that prioritises sustainability over issues of convenience, economy and popular perceptions.

It is a paradox that many Asian countries have some of the best native tropical hardwoods, yet face a shift away from their sustainable utilisation. Paradoxically on the other hand, many countries in colder zones in Europe, North America and Australia with largely native softwood timber supply extensively use timber as the prime building material in house construction. This is possible largely because of formal sector policy safeguarding the timber industry and this is one area that offers a learning opportunity for Asian countries.

Approaches towards sustaining the use of organic building materials such as timber and bamboo cannot be promoted during an exigent post-disaster situation; it has to be part of a long-term strategy practiced and continued in the context of a country's, or even region's, development plan. Some suggestions, although perhaps extending beyond the scope of this paper, are outlined below as a possible basis for informing, formulating and implementing sustainable planning initiatives:

- Development of industries specifically for organic building materials should be incorporated into the formal sector. In most Asian countries, such industries function to a large extent within the informal sector, and hence do not benefit directly from scientific innovations, quality control and regulated distribution channels.
- Such industries should be linked to production of renewable organic materials supply. Deforested areas can be reforested under agroforestry schemes specifically for renewable products suitable for use in buildings. Being part of a systematic planning initiative would allow regulating excessive profiteering, and illegal and indiscriminate harvesting.
- Incentives should be provided to local entrepreneurs for developing and sustaining organic materials industries including soft loans, microcredit programmes and tax breaks. Community based organisations could play an important role in this regard by linking local entrepreneurs to the formal sector.
- Incentives should be provided to scientists and researchers to develop environmentally friendly and contextually appropriate ideas for production, cultivation and processing of organic building products, as well as using them in practical and cost-effective ways for building houses. Measures should be taken so that these ideas do not remain confined within the institutional perimeter, but find application in the field.
- Treatment processes to increase the lifespan of organic products to reduce pressure on the supply base should be promoted. Toxic and environmentally hazardous chemicals should be avoided, or their use should be regulated through safe handling and disposal procedures.
- International trade trends that exploit natural resources in Asia should be identified and addressed. In this regard, export alternatives to timber should be conceived and developed.
- Environmental taxation of brick and cement industries to restrict their uncontrolled production and negative environment impact should be implemented, so that organic materials industries can gain ground in the market. Additionally, import of these masonry products should be limited and regulated.
- Designing and constructing buildings with organic materials are skills that are diminishing in many Asian countries in the face of rising predominance of construction with industrialised products. Within the policy framework of regeneration of the supply base and micro-industrial development, training of professionals, construction workers, carpenters and craftspersons should be incorporated for effective and efficient utilization of organic building materials.
- A robust organic building products sub-sector within the formal industrial sector would allow access to large supplies to fulfil the requirements during post-disaster reconstruction. The absence of such a strong sub-sector in post-tsunami Aceh led to a crisis that development agencies sought to address by building bungalow type houses, which in turn further undermined the possibility of its development. If such a sub-sector is developed, it can be anticipated that future disasters would not have such an unsustainable impact.

There would be a suite of hurdles in implementing these suggestions, requiring a long-term approach by making incremental progress. The suggestions may appear be too exhaustive to implement, but their comprehensive nature points towards the need for a holistic framework that includes a wide range of stakeholders and actions that support each other. However before this happens, there is need for awareness for such a framework and recognition of its necessity for environmental sustainability in the Asian region, which is generally lacking. This paper has been written

with a view towards contributing toward such awareness and recognition of the value of sustainable house building processes.

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