HOUSING RECONSTRUCTION IN ACEH: RELATIONSHIPS BETWEEN HOUSE TYPE AND ENVIRONMENTAL SUSTAINABILITY

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Abstract

In the aftermath of the December 2004 Indian Ocean Tsunami, housing reconstruction agencies typically engaged specialist contractors to build multiple houses using mass-produced construction materials. The dominant house type built by reconstruction agencies followed the ubiquitous 'bungalow' model and was constructed with industrialised materials. Other types were hybrid models that used the industrialised materials but traditional 'house on stilts' typologies. In Aceh, Indonesia, the adoption of these types extended existing trends away from vernacular traditions and materials such as timber and bamboo. While it can be argued that this mass housing introduced efficiencies of procurement, scale and cost, the long-term sustainability of these houses must not be overlooked if this type is to be portrayed as a suitable response to this type of humanitarian disaster – particularly as these types will define the future housing culture.

This research questions the sustainability of three houses built by reconstruction agencies in Aceh and makes comparisons with a typical timber vernacular house. As a measure of sustainability it quantifies two forms of life-cycle costing – the greenhouse gas (CO2) emissions and the ecological footprint of each of the selected house types. Results demonstrate that reconstruction houses are linked with levels of greenhouse gas emissions up to fifty times higher than traditional types and triple the ecological footprint of traditional types. This increase is primarily due to the overwhelming use of externally procured and imported construction technologies and mass-produced materials.

Keywords: Tsunami Reconstruction; Housing Sustainability; Life-Cycle Analysis; Greenhouse Emissions; Ecological Footprint.

Introduction

The housing culture of Southeast Asia, including the Daerah Istimewa Aceh (Special Region of Aceh), traditionally utilised organic building materials for construction such as timber, thatched grasses, and bamboo. The region's isolation from Indonesia's major population centres and economic base kept housing demands at relatively low levels. Land availability was high, resources were plentiful, and the vernacular construction systems did not unduly compromise the local environment. For many generations the local housing systems developed closely with the cultural needs and remained relatively sustainable.

More recently, within the last generation, a series of economic and cultural shifts have taken place that, amongst other things, have reconfigured local approaches to housing. Logging contractors have stripped local forests and the resultant high timber prices are linked to deforestation, industrialisation, overpopulation, and corruption (Dauvergne 1997, Food and Agricultural Organisation of the United Nation 2001, Global Witness 2002). Within the Aceh region quality timber is now expensive and is commonly only available in lengths that are shorter than those customarily required for house construction (Nas 2003). Furthermore the new aspirations of inhabitants have also led to new housing forms. Regionally it has been noted that access to television has introduced new living patterns and aspirations closely connected to consumerism, new lifestyles, and new forms of housing (Ockey 1999, Hamilton 1992, Askew 2002).

The masonry bungalow, the typical model promoted by the media, is now commonplace throughout Southeast Asia. Nas (2003) argues that the motivations that lead to contemporary bungalow housing types in Aceh include diminished access to suitable timber supplies, lack of craftspersons skilled in traditional construction techniques, and the notion that the traditional house is less ‘practical’ than its contemporary alternative. On a less tangible level Nas suggests that people are expressing an ‘interest in change and wish to keep up with the times’, and that ‘modernization and the availability of modern building materials such as brick and concrete stimulate people to alter their immediate living environment’ (Nas 2003). Changes to the housing culture are fuelled both by pragmatic concerns and by the desire to relate to an ideal of modernity emanating from industrialised and consumerist cultures – often from urban cultures manifesting within the same country.

The 2004 Indian Ocean Tsunami dramatically exacerbated these changes to the Acehnese housing culture. 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 have 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. While Roseberry (2008) identifies that the construction materials used in reconstruction are associated with high levels of embodied energy and embodied CO2, a close comparison between specific house types has not been undertaken.

Research methods

Research questions:

How does the sustainability of house types built by reconstruction agencies compare with each other and a traditional Acehnese house type? What are the greenhouse gas emissions and ecological footprints associated with each type?

This paper questions the relationship between house type and environmental sustainability, more specifically, the relationship between construction technologies and environmental impacts. In this study three houses, designed and built by development agencies as post-tsunami reconstruction housing for Aceh, have been selected and a Life Cycle Assessment (LCA) performed on those houses. The results from these houses are then compared with results from a typical traditional timber house in Aceh.

LCA is a technique for assessing the environmental aspects and potential impacts associated with a process – in this case a process that produces the four case-study houses. It calculates the effects that this process has on the environment over the entire period of its entire 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). After this step an evaluation is made using SimaPro – a computer program developed by PRe Consultants in the Netherlands and incorporating a database provided by the Center for Design at RMIT University, Australia. The SimaPro process incorporates a series of generalisations and assumptions, and is based on data from industrialised countries. Its value to this research is that it charts a transparent process that analyses each component of a system to enable quantifiable comparisons to be made. This data then enables researchers to compare the environmental sustainability of selected case-study houses.

Two measures of sustainability have been quantified - the carbon footprint and the ecological footprint. The carbon footprint is 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. The ecological footprint shows how much biologically productive land and water a house requires throughout its life-cycle.

These calculations are focused on the life-cycle costs associated with construction processes and running costs. The complexity of the calculation is high and certain boundaries must be placed around the study to make it feasible. For example, the SimaPro process includes the energy used by mechanical equipment used during the construction process but does not calculate the environmental costs of human labour – for example the environmental impact of the food consumed by the construction team during the building process. Further assumptions were made so as to be able to make direct comparisons. Firstly it is assumed that all houses have similar lifespans and that all have comparable electricity usage (calculated at two fluorescent lights, a small television set and two electric fans). Finally it is assumed that all will be recycled to a similar degree at the end of their lifespan. 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.

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. This analysis is based on Dall's series of drawings published in 'The traditional Acehnese house'.

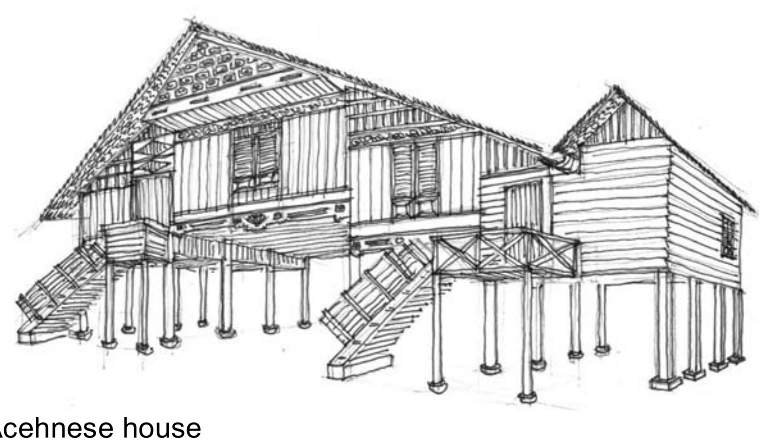

Fig. 1. Traditional Acehnese house

The house Dall describes is built almost entirely from organic building materials such as timber, bamboo and thatch. The house 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, major and minor 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 relaxation space, animal stalls and storage below.

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 wall footings. Walls are reinforced 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 coated with a sand/cement mix and painted. Door panels and frames are timber and window frames are aluminium with sliding operable glass panels. The gabled roof and gable ends are clad with corrugated iron sheet attached to a steel truss system.

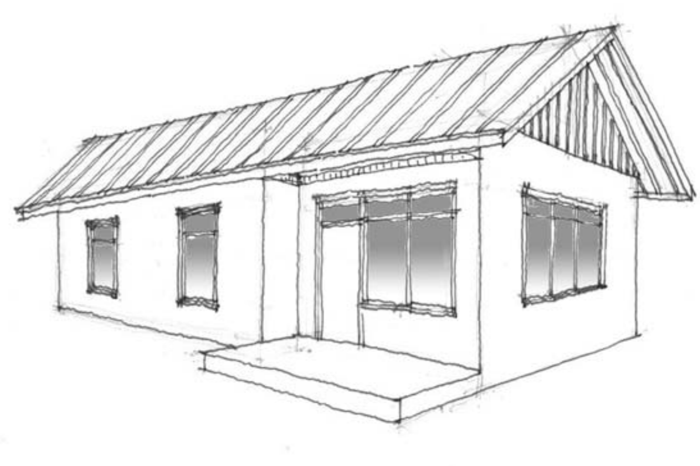

Fig. 2. Reconstruction house built by Caritas

The main entry into the house is through a covered porch into a combined living/dining room. The two bedrooms are accessible by an internal corridor leading out to the kitchen, toilet and then outside to the rear of the house. The total area of the house is 52m2.

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.

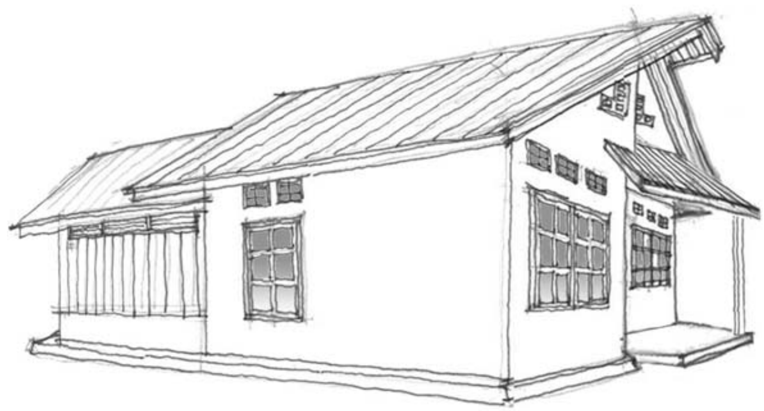

Fig. 3. Reconstruction house built by Habitat

The layout of the house follows a typical bungalow format – a front porch leads to a living/dining room and onto a pair of bedrooms. A kitchen and toilet are located at the rear as is an additional outdoor porch. The house covers a total area of 56m2.

House 4 - Uplink

Uplink houses were designed with two main types – one type is based on the bungalow format as described in Houses 2 and 3 whilst the other type is raised above ground on a series of stilts and forms a link with traditional Acehnese house typologies.

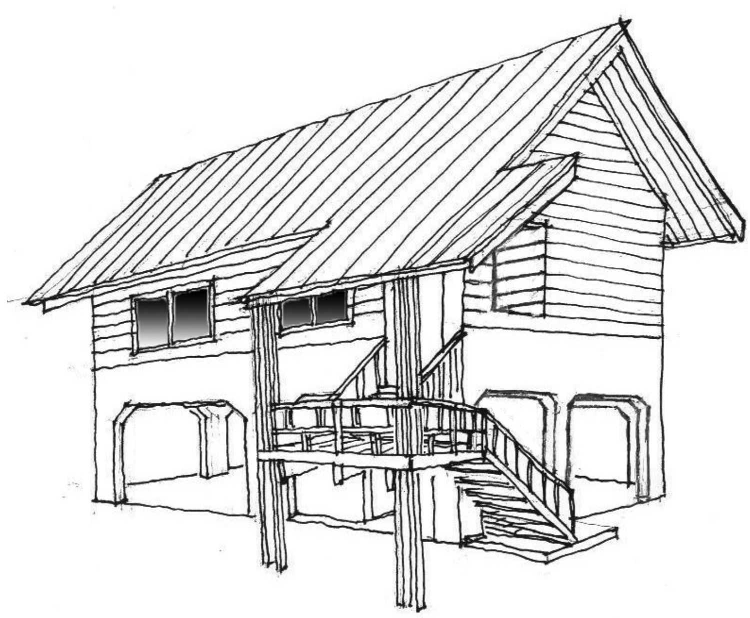

Fig. 4. Reconstruction house built by Uplink

This type uses reinforced concrete columns arranged in a grid and 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. 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 Acehnese houses. A timber staircase leads from the ground to the upper floor and includes a mid-level timber landing. All doors have timber panels and timber frames and windows are top-hung with glass panels and timber frames. Excluding the staircase this house covers 32m2 on each level.

Research Objectives:

The objective of the research is to provide a comparative analysis of the relationship between house type and environmental sustainability (as measured by greenhouse gas emissions and ecological footprint).

Research results

Many factors differentiate the four houses described above: types of materials, size, form and spatial arrangements. The first phase of the research measures the quantities of construction materials used to build each house. Each house has undergone an inventory analysis whereby every single construction component is quantified and recorded in cubic metres. Results are summarised in Table 1.

Table 1. Summary of material quantities (m^3)

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

Greenhouse gas emissions per house

Figure 5 compares the carbon dioxide (CO2) greenhouse gas emissions (measured in kilograms) associated with the construction and running costs of each of the four studied houses as described earlier in this paper.

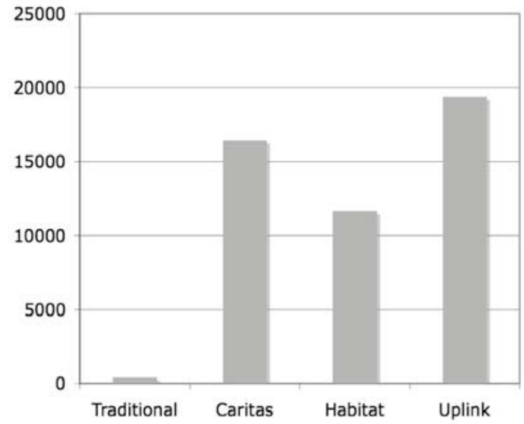

Fig. 5. Greenhouse gas emissions per house (kg CO2eq)

It reveals that the traditional timber house has an exceptionally low greenhouse impact as compared with the reconstruction types that demonstrate significantly 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.

Greenhouse gas emissions per square metre

The disparity between the construction type and quantity of emissions is further placed in perspective when considered on a per square metre basis. At $32m^2$ the Uplink house provides the smallest amount of enclosed space,- nearly one-third the amount as compared with the $90m^2$ traditional house. It would be most unlikely that the Uplink house, or for that matter either the Caritas or Habitat examples, could house as many residents as the larger traditional house. In the aftermath of any natural disaster, such as the tsunami, larger 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 evaluation of house type.

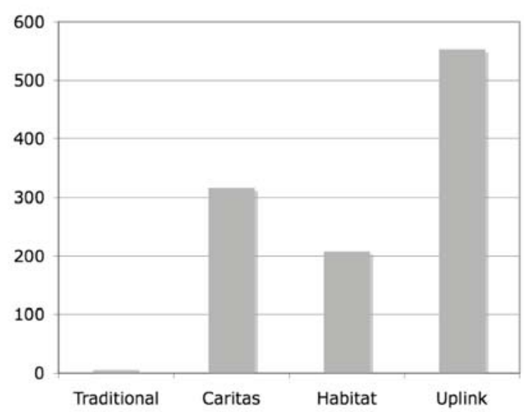

Fig. 6. Greenhouse gas emissions per square metre (kg CO2eq)

Figure 6 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 timber construction techniques as compared with contemporary construction techniques employing mass-produced materials. 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 one percent the emissions associated with the Uplink house, less that 1.5% of the Caritas house and less than 2.3% of the Habitat house.

Ecological footprint per house

Figure 7 compares the Ecological footprint associated with the construction and running costs of each of the four studied houses as described earlier in this paper. The ecological footprint shows how much biologically productive land and water a house requires throughout its life-cycle.

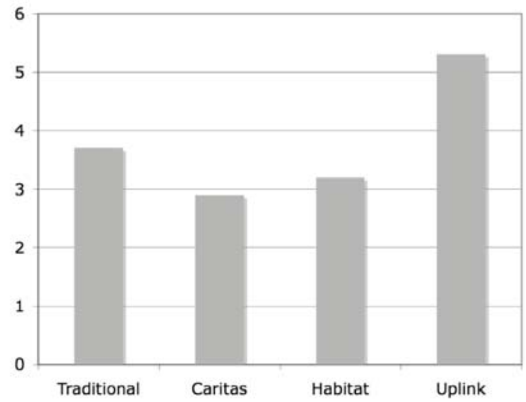

Fig. 7. Ecological footprint per house (hectares)

The traditional house has an environmental footprint of 3.7 hectares – meaning that 3.7 hectares of land is required to build and maintain the house throughout its life-cycle. Caritas and Habitat houses require marginally less at 2.9 and 3.2 hectares each respectively. The Uplink house requires the most number of hectares at 5.3. Therefore a single one hundred acre plot could support 27 traditional houses, 34 Caritas houses, 31 Habitat houses but only 19 Uplink houses.

Ecological footprint per square metre

Again it is useful to make comparisons on a per square metre basis given that each of the houses differ in size. On a per square metre basis the traditional house requires the least amount of land at 0.041 hectares with both the Caritas and Habitat houses requiring 0.055 and 0.057 hectares respectively. By contrast the Uplink house requires significantly more at 0.150 hectares.

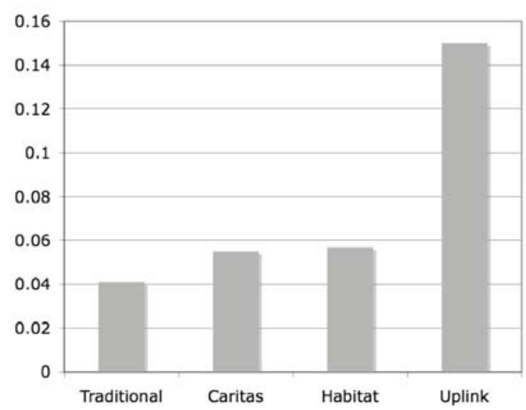

Fig. 8. Ecological footprint per square metre (hectares)

Therefore, a single one hundred acre plot could support 2439 square metres of traditional housing, 1818 square metres of Caritas housing, 1754 square metres of Habitat housing or 667 square metres of Uplink housing.

Discussion and conclusions

The two measures of sustainability outlined in this paper - CO_2 emissions and ecological footprints - confirm that traditional housing types constructed with locally harvested timber remains the key to reducing the environmental impacts associated with housing. This is particularly true when considering that CO_2 emissions stemming from timber production are negligible. Furthermore the ecological footprint of timber houses remains less than the mass-produced alternatives when considered on a per square metre basis.

However the lack of a sustainable local timber industry within Aceh, coupled with the demand for industrialised and 'Westernised' housing, required reconstruction housing to be constructed with externally procured imported materials and mass-produced products. This life-cycle assessment shows that these samples of reconstruction housing built by international agencies are all significantly less sustainable than traditional types.

Mass-produced industrialised materials dramatically increase CO_2 emissions, particularly products used in larger quantities such as reinforced concrete, concrete block, brick, and steel. The manufacturing processes that produce these materials require high levels of energy that in turn, contribute to the high CO_2 emissions.

The major limitation of this study is that it does not measure cultural appropriateness. The Uplink house, which measures poorly in quantitative terms, is most alike to the traditional house in its spatial planning. Both the traditional and Uplink houses are raised on stilts and provide additional sheltered space in their undercroft - space which could allow for additional living areas at low financial and environmental cost. This space could conceivably provide opportunities for residents beyond the scope of this research project's capacity to identify and evaluate. Furthermore a house raised on stilts is perhaps more likely to survive any possible future tsunami and would conceivably raise the chances for residents to survive this type of threat. The structure required to raise the Uplink house - reinforced concrete - has significant environmental impacts that raise the CO_2 emissions and ecological footprint associated with its construction. However the potential for improved cultural appropriateness and capacity for the house to withstand any future tsunami should be considered before a comprehensive judgement of these houses is made.

Key Lessons Learned

Timber is the more sustainable construction material as it is associated with significantly lower CO_2 emissions overall and a lower ecological footprint on a per square metre basis. Bungalow type reconstruction houses use considerably less construction materials than reconstruction houses built on stilts and are associated with lower CO_2 emissions and ecological footprints.

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Author's Biography

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Dominique Hes received a science degree from Melbourne University and followed this with a graduate diploma in Cleaner Production and a doctorate from RMIT University, Melbourne. Her research supports the integration of sustainability in building projects. Her research interests are to identify and fill the knowledge gaps in sustainability practice and application in the built environment.