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A NEW PARADIGM FOR SUSTAINABLE RESIDENTIAL BUILDINGS

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Summary
The development of mass-produced environmentally-benign housing is one of the critical factors in the transition to global sustainability. Such housing will need to be constructed from renewable and/or recycled materials, be conditioned using minimal or no conventional energy, and affordable. The need for such housing is urgent. In developing countries, their requirement is to house both growing squatter settlements, as well as those who have benefited from recent economic booms. In industrialised countries, there is a need for an alternative to the current resource- and energy-intensive housing.

Traditionally, mass housing construction can be characterised as skilled-labour intensive, and by on-site construction using non-recyclable materials with minimal prefabrication. This process is costly, can result in variable quality and is time-consuming. These houses are often constructed from a variety of materials including concrete, aluminium, steel and brick, which are energy-intensive to produce, resulting in a structure with high embodied energy content. A new design and building construct introduces Relocatable, Adaptive, Recyclable, and Environmental (R.A.R.E.) architectural concepts as a solution (Luther, Altomonte, Coulson, 2006).

This paper explores a new paradigm in housing, where dwellings will be pre-fabricated, modular, energy efficient, transportable and use renewable and/or recyclable resources. The paper reviews previous attempts to produce housing, which meets some of the criteria for this new paradigm. Their advantages and disadvantages are discussed. An approach towards a new type of modular prefabricated unit is proposed. A preliminary energy analysis, comparing a present relocatable classroom construction with one upgraded, is provided as an example towards low energy building operation. Finally, conclusions are drawn about the requirements of future housing if we are to progress towards sustainability.

1. Introduction
Globally there is a critical need for an environmentally sustainable mass-produced housing typology, which is both thermally comfortable and affordable. In some developing countries, squatter settlements range from 40-50%. In other developing countries, recent economic growth has fuelled a housing boom. Continued reliance on traditional housing solutions is environmentally unsustainable. Tiwari and Parikh (2000) analysed the impact on resources and carbon emissions of housing in India, if housing was provided to the estimated 15% of their population that currently has inadequate shelter. The present construction trend was found to be unsustainable from both a resource and environmental perspective if conventional materials (concrete, steel, aggregate and bricks) were used.

In Australia, current housing construction practice is unsustainable in terms of materials, energy for production as well as operation. The ecological footprint of the average Australian is approximately four times the level that is globally supportable (Simpson et al., 2000). Housing has become less affordable for the next generation of homebuyers (Age, 2006) and household sizes have been steadily declining for decades (Haberkorn et al., 2004). Scenarios of constrained choice, inappropriate housing options and continued heavy environmental impact are envisaged (AHURI, 2006). This study identified a set of values for policy development. These included: diversity i.e. housing forms that are flexible and accommodate the different needs and uses of society; affordability i.e. provision of dwellings that are appropriate for all incomes; and sustainability i.e. provision of housing that has a minimal impact on the environment. There is thus a convergence of the housing needs in developing and industrialised countries.

Previous mass housing construction in industrialised countries like Australia can be characterised by on-site construction, use of traditional materials and limited design variation. While some pre-fabrication (e.g. trusses) has been adopted by the traditional mass housing market, construction mainly takes place on site by various skilled tradespeople (bricklayers, carpenters, plumbers etc). This process is costly, requires skilled labour, results in variable quality and is time consuming. The houses are constructed almost exclusively from the traditional building materials, namely concrete, aluminium, steel, brick and timber, which
are energy-intensive to produce. Australia’s completed houses have high embodied energy content (Newton, 2001).

2. Towards a New Paradigm
A new paradigm in housing design, materials, construction, and its services is urgently required for environmental sustainability. A direction towards this architecture is outlined through eight Sustainable Building Categories (S.B.C.’s) presented in a Renewable, Adaptive, Recyclable and Environmental (R.A.R.E.) architecture (Altomonte and Luther, 2006). The purpose is for a project to strive towards success in all eight Sustainable Building Categories, in as much as possible.

- Biodiversity, Sustainable Site & Climate Analysis;
- Flexible & Adaptive Structural Systems;
- Renewable & Environmental Building Materials;
- Modular Building Systems;
- Innovative Building Envelope Systems;
- Renewable & Non-conventional Energy Systems;
- Innovative Heating, Ventilation & Air Conditioning;
- Water Collection & Storage Systems.

Other SBC’s are continuously being incorporated into the above list as they become acknowledged, for instance, daylight autonomy and optimised building control. When producing an effective design, the above SBC’s set a framework for ‘items’ to be seriously considered.

2.1 Modular and Prefabricated Design
Sustainable construction is in search of building system that can offer R.A.R.E. building principles. It is believed here that the revitalisation of an older paradigm – modular building – holds the answer to future construction. Such processes have tremendous potential over conventional systems regarding material use and waste minimisation. Today, robotic and pre-programmed building processes can offer ‘one-offs’ and unique diversity in pre-fabricated construction (Bock, 2007). One of the greatest intentions is to introduce modular renewable and sustainable building services into R.A.R.E. building principles.

Modular design is not new. The 1920’s to the early 60’s were full of inventors and innovations for modular construction and its on-site delivery. The ‘Turning Point of Building’ (Wachsmann, 1961) was an indication that such constructs would be the predecessor over conventional building processes, as we know them today. Relocatable school buildings represent one of the most popular forms of ‘modular’ construction today. Yet, the processes by which such buildings are manufactured, is a far cry from applying present technological advancements. There are significant opportunities to advance the entire modular design, its structure, building materials and most importantly services technology.

Figure 1 offers a diagrammatic analogy for the range of construction types and suggested flexibility offered by pre-fabricated building. This diagram is an attempt to organise the vast undefined chaos of modular building systems into some sort of categories. It is however, not intended to cast a specific modular system into a particular category, but rather to acknowledge various methods of construction. Most pre-fabricated buildings will in fact be a combination of several design construction systems.

2.2 Pre-fabrication, Materials and Recyclability
The mixed nature of building materials makes recycling of demolished buildings difficult and usually financially unprofitable. Hence large amounts of building waste are buried as landfill. It is estimated that 30-40% of all Australia’s solid waste disposed of at landfill sites comes from the construction and demolition of buildings (Newton, 2001). Mass-market housing developers have accommodated the differences in consumer choice by offering multiple design options e.g. 2, 3 or 4 bedrooms or superficial design variations e.g. facade. While offering some degree of flexibility, this approach is limited. Ultimate flexibility, and therefore choice, can be accommodated only if buildings are constructed in a modular component or kit-of-parts basis.
Prefabrication of building envelopes has taken off in North America through the use of Super Insulated Panels (SIP’s). The developments of such have advanced into the provision of the structural system within the panel itself. SIP buildings apply about 60% less timber than conventional frame construction. Their insulation properties are outstanding and the construction technique has substantially reduced unwanted infiltration in buildings.

One of the criticisms of SIP panels rests with its insulation material, applying polycyanurate and polyurethane materials that involve oil-based products, potential CFC emissions, and out-gassing. Several of these problems have been resolved and the post baking of the material has almost eliminated out-gassing. Yet, the recyclability of the material is debated. In lieu of this, one manufacture (in the U.S.A.) has produced a SIP with compressed straw and wheat fibres claiming an 80% recyclable produce with high insulation properties. Other home manufacturers, such as SALA homes (QLD) have been applying rice and straw based products (Durra board®) as the insulated wall material.

Another construction material with growing interest is paper. Cardboard structures have been applied to many packaging applications. One of the major drawbacks is their vulnerability to moisture and water damage. Recently, an Australian manufacturer has investigated cardboard door materials that consist of a corrugated 4mm layer to either side of a 25+mm thick paper honeycomb core structure. Both corrugated sides are filled with polyurethane in their flutes, yielding an incredible structural strength, moisture proofing and a higher insulation value. The company manufacturer, Ureflute claims environmental recyclability of the product. Such products as this, hold the key to future building, yet, require extended research input.

There is room for improvement in the search of benign products that provide our palette of construction materials. According to McDonough and Braungart (2002) our waste should equal food, and the building materials which are ‘edible’ will not be toxic. We need to also consider our application of materials and avoid mixing of manmade ones with those that are natural, in order to improve the capability of recyclability.

### 2.3 Relocatable and Adaptive

New design concepts, materials and construction techniques are essential for a new paradigm in housing. This paper explores progressive construction techniques, modularising and pre-fabricating building services and the application of benign (recyclable) materials. It follows a recently developed outline, a roadmap, towards developing a R.A.R.E. (renewable, adaptive, recyclable and environmental) responsive architecture. Several examples of previous research in this area are discussed with the idea of a particular concept – a renewable relocatable – introduced in greater detail. Design and material options, as well as the integration of services (water and energy) into the design. The results of some simulations are then presented. Some conclusions about further research directions for this building typology are finally suggested.

It is realised here that most of our buildings, unlike indigenous architecture, are static and permanent. Alternative structures consider structural systems that are flexible and removable like screw pile foundation systems. Too often our foundation methods resort to high embodied energy slab on grade concrete floors.

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**Figure 1: A Categorisation of Modular Pre-fabrication Systems and Construction Methods (Luther et al., 2007)**

<table>
<thead>
<tr>
<th>Modular Building Categories</th>
<th>Modular Design Systems</th>
<th>Modular Construction Stages</th>
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<td>Foundations</td>
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<tr>
<th>Panel/skin</th>
<th>Kit of Parts</th>
<th>Complete Unit</th>
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<td>Prefab</td>
<td>Fill-in</td>
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<td>Skeletal</td>
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<td>Cellular</td>
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There are several raised insulated timber floor construction methods being explored by the University of Tasmania School of Architecture through their test cell buildings.

In regards to relocatable and adaptive construction, it is believed that modular prefabricated design can deliver such. One of the most critical concerns is the connection points of vertical and horizontal building surfaces where potentially the most leakage can occur. The concept of building in elements that can be assembled and replaced is an important one and has been addressed by many of the pioneers of building, like John Prouve (Figure 2). Here the wall panels can be 'switched' or replaced with a selection of alternative making the building 'adaptive' to various climatic conditions.

2.4 Services

One of the most neglected areas of present design is the haphazard approach to which building services are integrated into the construction process. The services are one of the most labour intensive and costly items on a building project. It is therefore essential that these systems become integral components of design. In other words, they are a part of a designed system. Our present on-site installation of services, and specialised fabrication of connections is outdated and costly.

An example of such service integration is offered through an organization in Germany called Digitales Bauen, where all the services of a building are planned and divided into their 'least common denominator' (see Figure 3). This provides for actual pre-fabrication of entire service modules to be produced off-site and installed with minimal effort and interference of trades on-site. The approach guarantees performance and reduces operational failures and assures 'interference free' services.

Figure 2 The Tropical House by John Prouve

Figure 3 Total Integrated Building Services Planning (Digitales Bauen)
An example of integrating services is provided by a student project of a pre-fabricated modular house design by H. Pallot (Deakin University). This project, although not completely resolved, considered the services as complete ‘snap-in’ components. In this case the aim was for renewable services to be integrated into the housing design. Figure 4 shows the roof system as an energy (photovoltaic) generator, a hot water heater and a water collector. These systems are considered with an interior wall (service) component and storage into the floor foundation system.

Figure 4  Service Modules Integrated into a Building System (student project: H. Pallot, 2007)

3.0 Energy Consumption and Operational Concepts

The move towards renewable energy systems for our building systems is inevitable. We need to move forward on the concepts of Reduce, Reuse and Renewables. A study on energy and comfort measurements in relocatable school buildings (Fuller and Luther, 2003) prompted further research studies into energy conservation. An energy simulation conducted for a two-classroom relocatable school building, indicated that up to a 50% improvement in the consumption of fossil fuels is reasonably achievable (Figure 5). Once this energy reduction has been realised, two aspects need to be considered: solar thermal processes and renewable energy generating systems.

Figure 5  Annual energy consumption comparison for a reference and an energy efficient relocatable school building (ENERGY-10 simulation).
Figure 5 highlights (circled) the items that could be accommodated to a large extent through solar thermal processes. These would require minimal electric energy input. Finally, the application of photoelectric panels that cover the remaining required needs of electricity is considered. Furthermore, it is interesting to note that if only 98% of the peak hourly demand electricity load was acceptable, the original peak demand load would be reduced by 50% (Figure 6).

Another important and often overlooked aspect of energy consumption is due to leaky and unpredictable construction techniques. This issue has been researched in Australia by Air Barrier Technologies and the Mobile Architecture and Building Laboratory (MABEL). Buildings in Australia are often 2-4 times leakier than European countries (Luther, 2007). The simulation results provided by the ENERGY-10 program (Balcomb, 1998) indicate infiltration as one of the top three energy saving strategies (see Figure 7).

4. Conclusions
The development of mass-produced environmentally-benign housing is one of the critical factors in the transition to global sustainability. This new housing will have to be made from renewable and/or recycled materials, be naturally conditioned and affordable. The need for such housing is urgent. In developing countries, their requirement is to house both growing squatter settlements, as well as those who have
benefited from recent economic booms. In industrialised countries, there is a need for an alternative to the current resource and energy-intensive housing.

A new approach towards sustainable housing, suggesting methods of prefabricated modular construction, recyclable materials, reducing energy consumption and introducing renewable energy has been outlined. The criterion for designing sustainable, renewable and adaptive buildings has also been introduced. The entire construction industry merits a re-visit in its methods and processes if we are to assure affordable and sustainable buildings for our future. Several of these methods have been presented in this paper.

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References


