Second International Conference on Construction in the 21st Century (CITC-II)
"Sustainability and Innovation in Management and Technology"
10-12 December, 2003, Hong Kong

A Comparative Sustainability Assessment of Steel & Concrete Framed Housing Blocks in Hong Kong

Dr. Alex Amato
Assistant Professor, Dept. of Architecture, The University of Hong Kong, Hong Kong SAR, China

Prof. Richard Frewer
Chair Professor, Dept. of Architecture, The University of Hong Kong, Hong Kong SAR, China

Mr. Steven Humphrey
Associate Director, Davis Langdon and Seah Management Ltd. (HK office), Hong Kong SAR, China

Abstract
This study will comparatively assess the sustainable performance of public and private sector standard housing blocks in Hong Kong. Comparisons will be made between each of the selected building types using the following indicators:-

- cost:- capital/in-use
- energy & CO_2 – embodied
- energy & CO_2 - in-use
- construction waste

As the relative significance of environmental impacts emerge, it will give clear indications of where to concentrate the industry's efforts in reducing or mitigating serious impacts.
The Integer Tower proposes to use prefabricated precast modular units that form the individual living units. These are stacked upon each other, three storeys at a time inside a steel mega-frame, which provides a platform for each 3-storey section of the building. Mass production of the modular units could also have great economic benefits for the future provision of housing in Mainland China. Previous work carried out has shown the potential benefits of the extensive reuse of construction products in terms of the reduction of embodied impacts.[i] The consequences to the construction sector and the market barriers to the wide scale adoption of reusing construction elements and components have also been assessed.[ii]
The methodology will give designers, contractors and developers a relative inexpensive means of quantitatively testing their sustainable construction conjectures.
The initial study will build upon work recently carried out by Davis Langdon & Seah Management Ltd. that compared the cost of the main structure in standard public and private housing blocks and work carried out in the UK by the Steel Construction Institute.[iii] [iv]

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[i] AMATO, A.,:- '***Appraising the Impacts on the Construction Sector of Adopting a Quantitative Methodology for Assessing Recyclable & Reusable Construction Products'*:-** paper presented at and published in the proceedings of the Italian National Steel Construction Conference in Naples, October 1999.
[ii] HKUST & DAVIS LANGDON & SEAH HONG KONG LTD., :- ***Cost Efficiency of Structural Designs of Standard Domestic Blocks'*** presented to the Hong Kong Housing Authority, July 1999
[iii] HKUST & DAVIS LANGDON & SEAH HONG KONG LTD., :- ***Cost Efficiency of Structural Designs of Standard Domestic Blocks'*** presented to the Hong Kong Housing Authority, July 1999
[iv] AMATO, A.,:- ***'A Comparative Environmental Appraisal of Alternative Framing Systems for Offices',*** published by Oxford Brookes University U.K., July 1996.

Keywords
Hong Kong, Life Cycle Assessment (LCA), Life Cycle Costing (LCC), longevity, operational regime, repair and maintenance regime, residential construction, South China, sustainability.

1. Introduction

This paper reports the progress of the first of two related studies: the first is complete and a second is approximately two thirds complete. Both studies endeavour to establish an internationally recognised methodology to undertake comparative assessments of the relative 'sustainability' of buildings and civil engineering projects. Methodology devised to achieve this, must be specifically tailored to Hong Kong's Construction Industry, and thereafter must be made applicable to the broader South East Asia Region. Hong Kong and the South China region are strongly driven by costs so, in this context, Life Cycle Costing (LCC) must be included in any assessment, together with Life Cycle Assessment (LCA). In both studies, two of the three recognised environmental aspects of sustainability are measured: economics and environment. The third, the social impact, has been excluded because of a present lack of data, the difficulty in setting the scope of such a study, and setting recognised and appropriate 'yardsticks' within Hong Kong to measure social indicators. The intention is to focus on social indicators in future work.

The first study sought to demonstrate to key Construction Industry representatives and 'stake holders' the implementation of a methodology by undertaking a comparative assessment of archetypical residential towers in Hong Kong. Two existing towers, one private the other public, were selected together with one future or "concept" tower. The presentation was less to do with highlighting differences between the buildings being analysed and more a demonstration of how the methodology can be used as:-

- a means to inform the debate on the macro scale about how comparative construction methods and hence how housing types might evolve in the light of LCA/LCC data;
- a tool of use to client bodies to analyse their property portfolio, by design teams on projects and manufacturers on improving their products.

The study compared the environmental and cost performance of the following three 40-storey residential tower types: -

- a housing authority 'standard' harmony block;
- a private sector housing block;
- the Integer Concept Tower [1].

2. Introduction of Ongoing Work

The second study focuses on the New Harmony Block[v] and is for the Hong Kong Housing Auhtority (HKHA).
The outcome is a combined LCA/LCC decision making tool specially for assessment of the New Harmony Block (Option 2). The integration of LCA and LCC methodology is based on quantitative assessment and therefore is more accurate than the qualitative building environmental assessment method currently available that are often based on check-box assessment methods, such as Hong Kong Building Environmental Assessment Method (HK-BEAM) and BRE's Environmental Assessment Method (BREEAM). Building designers can therefore evaluate precisely and objectively the relative sustainability and cost effectiveness of their material selections from a whole life-cycle perspective. The life cycle perspective includes all stages such as raw material extraction, manufacturing, transportation, construction, operation, and maintenance, disposal and recycling.

[v] The 41-storey residential Harmony Block comprises 20 units per floors as shown in figure 1 and 2: 4 flats 1P/2P, 8 flats 1B, and 8 flats 2B.

The LCA/LCC decision making tool measures and quantifies the following ten environmental impacts for each life-cycle stage:

- Energy (GJ)
- Resource depletion (tonnes)
- Water consumption (cubic metres)
- Waste (tonnes)
- Climate change (tonnes CO_2 eq.)
- Acid rain (kg SO_2 eq.)
- Photochemical smog (kg ethane eq.)
- Ozone depletion (kg CFC-11 eq.)
- Toxicity to humans (kg Tox eq.)
- Toxicity to ecosystems (kg Tox eq.)

"For each category of impact, characterization will be taken to define the contribution of an environmental burden (intervention) to the impact. The purpose of this is to translate different inventory inputs into directly comparable impact indicators. For example, characterization would provide an estimate of the relative human toxicity between lead and zinc. One burden which makes a contribution which is considered to have a contribution to that impact, or 'potency', of 1. Other burdens are considered with a potency factor relative to that. Alternatively, the burden can be characterized by measuring it in a particular unit, such as cubic meters of water. The characterization process follows international practices in the characterization of inventory data for their potency with the different impact categories.
The characterized impact will then be normalized. The purpose is to express impact indicator data in a way that can be compared among impact categories. The procedures normalized the characterized results by dividing by selected reference values, which can be:

- The total emissions or resource use for region that may be local, regional or global
- The total emissions or resource use for an area on a per capita basis" (Howard *et al*., 1999).

The normalized impact should be weighted before comparisons can be made between different specifications. If the potential impacts for two different impact categories are equally large after normalization, the weighting process which reflects the perceived relative seriousness to each impact category is used to assess the difference between each impact. The assessment is based on workshops carried out in October 2002 that canvassed views from a whole range of Hong Kong construction industry representatives who ranked the relative seriousness of the ten impact categories. The weighted impacts will be totalled and form a unitised Hong Kong Environ-Point, an environmental impact indicator for the combined LCA/LCC study.

3. Methodology – First Study
There are 4 stages:-

- data gathering and selection of performance indicators
- creating life-cycle models for each building type (3Nº) and for each sustainable indicator (4Nº) i.e. 12 separate models in total;
- carrying out the comparative analysis once all the data has been delivered;
- development of both practical and possible improvement strategies with their associated cost and environmental benefits then being critically analysed.

4. Some Initial Results – First Study
The results given in Table 1 are a sample of the comparative data obtained from the modelling process. Comparative figures were obtained for energy and these showed that the ICT was very sensitive to the material embodied energy for steel and to the overall flexibility of the building i.e. whether the building

would actually last for 50 or 75 years – 25 years longer was one of the primary assumptions put forward by the designers of the ICT. When regarding all of the results it must be remembered that the ICT is just that; a concept, not a real building while the other two blocks are. Furthermore the Housing Authority Block is the current end result of an evolutionary process of considerable refinement and there is no doubt that it is extremely cost and material efficient.

Table 1. Embodied Energy For Various Life Cycle Stages.

Environmental Indicator Category	Housing Authority Standard Block *50 years*	Private Sector Standard Block *50 years*	Integer Concept Tower *50 years*	Integer Concept Tower *75 years*
Energy (MJ/m^2 CFA)				
• Initial	6,058	8,708	8,619	8,619
• Repair & Maintenance	8,052	12,128	10,282	15,423
• Operational Energy	17,733	12,836	13,407	18,187
• Demolition and decommissioning	56	83	56	56
Life Cycle Total	**31,899**	**33,755**	**32,364**	**42,285**
Rate per Annum	**709**	**750**	**719**	**563**
Nº of occupants per building	3,196	645	594	594
Annual rate per occupant	**0.22**	**1.16**	**1.21**	**0.95**

Having said the above the overall energy performance of the Integer Concept Tower (ICT) lies between the Housing Authority Block (HAB) and the Private Sector Block (PSB) and when amortized over the 75-year life, its rate per annum is best. The initial embodied energy of the ICT however is worst and indeed shoots up to 11,650 MJ/m2 CFA when 32GJ/tonne is the input figure used for structural steel and not the 13.5GJ/tonne figure used above for all the other steel items. A range from 32 GJ/tonne (primary raw materials) to 9.8 GJ/tonne was analysed; finally, a life cycle figure of 13.58 GJ/tonne was used in the figures shown above. This methodology is in accordance with the sensitivity analysis established by previous work (AMATO, 1996). The other noteworthy point is the significance of the operational energy figures, in relation to the initial and repair and maintenance figures, it is about equal to the total of both the construction of the building in the first place and repairing the building fabric during its life.

However it would seem that the repair and maintenance regime (R&MR) of all the housing blocks is considerable, over 30% more than the construction of the building in the first place for the HAB and while the R&MR for the ICT is only approximately 25% of the initial figure very interestingly it is almost 50% more for the PSB. The question that emerges is why the R&MR values should be so much in comparison with the initial values. This and explanations of why the proportional figures (from 25% - 50%) should also vary considerably over the range of building types will be analysed comparatively with other international work in the future but have yet to be carried out and will occur at the end of this study.

Finally the buildings have very different occupancies and so at the end of each parameter the ***annual rate per occupant*** is shown. Clearly the HAB emerges as being extremely efficient in this respect and the Housing Authority can take some pride in this achievement. However this does provoke a long-term concern about people's aspirations to future standards and whether the desire for greater space and consumptions standards will inexorably drive the occupants now housed in the HAB to demand a 'consumption level' that is more similar to those enjoyed in the PSB. If this view is taken the ICT over 75 years does seem to offer the best long term solution.

Similar results were obtained for waste, see Table 2, where again the quantity of steel was significant as this time the steel frame was recycled and reduced the total quantity of waste going to landfill. It should be remembered that at present the waste figures are calculated by volume and not mass and greater differences might emerge between the Integer Concept Tower and the existing concrete housing blocks as the mass of steel is more than concrete.

Table 2. Waste Volume Figures For Various Life Cycle Stages.

Environmental Indicator Category	**Housing Authority Standard Block** *50 years*	**Private Sector Standard Block** *50 years*	**Integer Concept Tower** *50 years*	**Integer Concept Tower** *75 years*
Waste – volume (dm^3/m^2 CFA)				
• Volume to Landfill Initial	38.00	29.24	18.04	18.04
• Volume to Landfill Deconstruction	899.80	1,022.47	857.43	857.43
• **Recycled Materials**	**17.87**	**28.14**	**42.15**	**42.15**
Life Cycle Total Waste (dm^3/m^2 CFA)	**920**	**1024**	**833**	**833**
1. **LIFE CYCLE TOTAL WASTE (MASS)**	*34,361 tonnes*	*20,088 tonnes*	*22,548 tonnes*	*22,548 tonnes*
Rate per Annum	**20.84**	**23.37**	**19.45**	**12.51**
Nº of occupants per building	3,196	645	594	594
Annual rate per occupant	**0.007**	**0.036**	**0.033**	**0.021**

It appears that the best performing building type for the waste indicator is the ICT, over the 50 and 75-year life. It has been assumed that all the metals for all the buildings will be recycled and because there is a considerably greater tonnage of metals (structural steel) in the ITC, this has had the effect of considerably boosting the amount recycled and thus reduced the amount going to landfill. Also the effect of amortizing the building over another 50% more of its life again considerably reduces the rate per annum, a peculiar concept perhaps, as a building is not demolished in yearly stages, but is applicable on a larger citywide scale.

Table 3. Quantities Of CO_2 At Various Life Cycle Stages

Environmental Indicator Category	Housing Authority Standard Block *50 years*	**Private Sector Standard Block** *50 years*	**Integer Concept Tower** *50 years*	**Integer Concept Tower** *75 years*
CO_2 (kg/m^2 CFA)				
• Initial	987	1,527	1,522	1,633
• Repair & Maintenance	2,131	2,245	2,044	3,066
• Operational CO2 due to energy consumption	2,963	2,145	2,241	3,361
• Demolition & Decommissioning	*	*	*	*
Life Cycle Total	**6,082**	**5,918**	**5,808**	**8,060**
Rate per Annum	**135**	**132**	**129**	**107**
Nº of occupants per building	3,196	645	594	594
Annual rate per occupant	**0.04**	**0.20**	**0.22**	**0.18**

*Carbon dioxide values were unable to be reliably calculated for the demolition process, as the energy consumption and fuel mix attributable to the transport of waste material to disposal sites was found to be extremely variable for the examples investigated. However CO_2 emission resultant from the demolition process are likely to be of a similar order as those for energy i.e. very much smaller when compared with the initial and overall life-cycle totals.

Here again the figures presented in Table 3 show the ITC is the overall best performing building but the most striking aspect of the above results is the predominance of the operational CO_2 emissions.

Table 4. Cost Figures For Various Life Cycle Stages.

Economic Indicator Category	Housing Authority Standard Block *50 years*	**Private Sector Standard Block** *50 years*	**Integer Concept** *50 years*	**Integer Concept** *75 years*
Cost ($\$/m^2$ CFA)				
• Capital	5,354	8,084	11,083	10,130
• Repair & Maintenance	4,185	4,859	4,279	4,490
• Operational Costs (management)	2,835	5,177	3,837	5,810
• Operational Energy Cost	6,545	4,525	4,441	7,350
• Demolition & Decommissioning Costs	47	90	39	60
Whole Life Costs	**18,965**	**22,736**	**23,678**	**27,840**
Rate per Annum	**421**	**505**	**526**	**398**
Nº of occupants per building	3,196	645	594	594
Annual rate per occupant	**0.13**	**0.78**	**0.89**	**0.67**

Interestingly the cost indicator, as shown in Table 4, appears to mirror the energy results.

5. Conclusions

- Longevity is important and the ICT becomes the best performer over all the indicators in the 75-year life assessment. The presumption here is that it will have a 75-year life because of its intrinsic flexibility of its frame construction. Whether this same flexibility and thus extension of overall building life can also be achieved in reality by the other two standard blocks is out with the scope of this study. But redundancy is seldom caused by the basic constructional materials losing their functional integrity and nearly always to do with the economics of flexibility. As Hong Kong's GDP increases it is very likely that tenants once content with space standards that would be considered in many other countries to be small may well demand/desire greater habitable floor area. If this cannot be achieved by the refurbishment of buildings due to the inherent inflexibility of say load bearing cross-wall type construction then building design ought to be changed to facilitate/maximise flexibility.
- A process of benchmarking of the complete range of Hong Kong's building types ought now to be undertaken so that best practice standards can become design targets.
- The operational regime is significant for all the buildings and energy efficiency is clearly important and strategies to reduce demand and supply with energy generated renewably should be examined.
- The repair and maintenance regime is also very significant indicating that varying and improving how the building is run and maintained could potentially considerably reduce the overall life cycle impacts.
- The Integer Concept Tower is definitely worthy of further investigation.
- The models can now be interrogated to review a whole series of design questions. For example:-
  - *At what point would the inclusion of photo voltaic façade cladding be cost effective or conversely, how much would the price of energy have to rise to make its inclusion paid for in say 10 years.*
  - *A similar question could be posed for insulation.*
  - *If the layout (plan form) of the buildings were rationalise what would be the consequence.*
  - *Perhaps the largest question to be raised in Hong Kong's construction sector at present is the extent and potential of the use of precast elements. Here a range of alternatives can be explored and the proposals optimised.*

6. Ongoing Work

The first study is now almost complete, the bulk of the work being the creation of the building models. However the following points below are a direct outcome from the first study and these have yet to be initiated: -

- The operational energy and CO_2 model requires greater validation. The figures that have been derived are correct, but there now remains the task of establishing a representative range of results that reflect the range of lifestyles of the different types of tenants, sizes of families etc. It is also desirable to have a better understanding of future energy demand and supply trends, and especially of the significance of how energy demand is affected by energy cost.
- The current practice of recycling materials in Hong Kong needs further understanding so that the end-of-life waste stream to landfill can be more accurately calculated.
- A sensitivity analysis needs to be carried out using a range of methods to assess the benefit of future recyclability of materials, especially steel. This has been shown to make a significant difference to the comparative analysis of concrete and steel frame alternatives.
- Following this is to bring forward the debate about whether recycled and reused construction materials are going to make a significant contribution to minimising the flow of waste.

7. References

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