

A comparative sustainability assessment of standard housing blocks in Hong Kong and proposed integer concept tower alternative

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Abstract: This study is a comparative assessment of the relative sustainability of three Hong Kong 40-storey residential tower types: a housing authority "standard" Harmony Block (HAB), a private sector housing block (PSB), and the Integer Concept Tower (ICT) (50-year and 75-year life). The ICT is a demonstration project showing how a future residential tower of 40 stories might be designed and built for a more sustainable construction industry in Hong Kong. In this study, Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) are combined together to measure two of the three accepted environmental aspects of sustainability: economics and environment; using an internationally recognized methodology specially tailored to Hong Kong construction industry, including the South East Asia Region.

According to the result study, the overall energy performance of the ICT lies between the HAB (0.22 MJ/m² CFA/annum/occupant) and the PSB (1.16 MJ/m² CFA/annum/occupant) with 0.95 MJ/m² CFA/annum/occupant over 75-year life, and when amortized over 75-year life its rate per annum is best with 563 MJ/m² CFA/annum (versus 709 for HAB and 750 for PSB). The annual rate per occupant of embodied energy is extremely efficient in the HAB. The ICT is the best performing building type for the waste indicator, over the 50 and 75-year life with respectively 19.45 and 12.51 dm³/m² CFA/annum (against 20.84 for HAB and 23.37 for PSB). The results show that the ITC is the overall best performing building with 129 and 107 CO₂ kg/m² CFA/annum over 50 and 75-year life respectively, but the most striking aspect of the results is the predominance of the operational CO₂ emissions. Also, the cost indicator appears to mirror the energy results.

In this study, the ITC becomes the best performer over all the indicators in the 75-year life assessment, showing the importance of the following three main issues: longevity, allowing for better frame construction flexibility; energy efficiency, minimizing energy consumption and increasing the use of energy from renewable generation sources; and repair and maintenance regime efficiency, which affects the whole life cycle impacts. The Integer Concept Tower is definitely worthy of further investigation.

Keywords: Hong Kong, life cycle assessment (LCA), life cycle costing (LCC), sustainability.

1. Introduction

This paper reports the progress of the LCA and LCC study. The study endeavours 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 the study, 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 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:

- 1) 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;

- 2) 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 (HAB);
- ♦ a private sector housing block (PSB);
- ♦ the Integer Concept Tower (ICT).

2. Methodology

There are 4 stages:

- 1) data gathering and selection of performance indicators;
- 2) creating life-cycle models for each building type (3N°) and for each sustainable indicator (4N°) i.e. 12 separate models in total;
- 3) carrying out the comparative analysis once all the data has been delivered;
- 4) development of both practical and possible improvement strategies with their associated cost and environmental benefits then being critically analyzed.

3. Data gathering

In order to carry out a comparative LCA/LCC assessment throughout the full life cycle of each building type implies the availability of a comprehensive database of the costs and environmental impacts. These impacts are resultant from the manufacture and delivery of all the major construction materials, elements and components. For the first study initial investigation showed that much published environmental material data had been generated in Europe or Australia. However the 'regionalisation' of data for South East Asia or the procurement of validated regional data was considered important. For this reason it was decided to restrict the European embodied energy of construction materials data to the role of a comparative validation of the only 'localized' database published (really international data considered to be applicable for use in Hong Kong). This 'local' data was restricted to the embodied energy of a range of key construction materials (Chen, Burnett, & Chau, 2000). The comparison of European and 'local' HK embodied energy data showed little difference and thus the European CO₂ (largely emissions resultant from energy generation) data was considered to be appli-

cable, although these will be adjusted in accordance with Hong Kong's slightly different fuel mix in the next iteration of this study.

However good local data on the operational energy consumption per building (the energy consumed during the operational life of the building – cooling, ventilation lifts etc.) were available as were reasonable local data on the material consumed in the repair and maintenance regimes. Good local data were also available for waste and together with the above data it was then possible to create a reasonably good life-cycle model that assessed the environmental indicators mentioned below.

Finally very good local cost data were available throughout the building life cycle and thus the study was able to create building life-cycle models for each building type using the indicators listed below (including the reasons for their selection). Thus the assessment took into account all the buildings' full life cycle, from the manufacture of the building components and elements from raw materials, through the construction and operational life of the buildings and finally to the end of the buildings' lives. Assumptions had to be made of course about the maintenance regime of the Integer Tower. The performance of each building type was then compared in terms of the following indicators:

- ♦ Energy both embodied and operational:- because energy is a robust indicator of environmental impact and crudely assess impacts to the biosphere which other indicators below do not. It measures global impacts in the sense that it is a resource that is being depleted. Moreover, data are available.
- ♦ CO₂ both embodied and operational:- because it is an indicator of greenhouse warming a global impact and data are available. If further emissions data were available from other studies then it would be desirable to go through a process of characterization to create a greenhouse forcing impact index. Global warming is recognized by many in the environmental movement as perhaps the most serious threat to sustainability. Again, data were available.
- ♦ Waste differentiating between mass going to landfill and mass recycled or reused. This is a local issue - consumption of scarce local resource i.e. landfill. Nevertheless, it is considered important as estimations of the quantity of waste

annually produced in HK are predicted to rise geometrically. Very accurate data has emerged from the inventory analysis proposed (Koenig, Kwan, Lee, & Liu, 2001).

Finally cost because not only is it the basis of many if not most construction decisions in Hong Kong but it is also a key economic indicator and goes much of the way to satisfying the economic perspective required to obtain an assessment in terms of sustainability.

4. Results

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.

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 13.5 GJ/t figure used above for all the other steel items. A range from 32 GJ/t (primary raw materials) to 9.8 GJ/t was analyzed; finally, a life cycle figure of 13.58 GJ/t 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.

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 ICT, 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.

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 CO₂ 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 CO₂ emissions.

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

Table 1. Embodied energy for various life cycle stages.

Environmental indicator category	Energy in stages /(MJ/m ²)				Total life cycle Energy/(MJ/m ²)	Annual energy rate/(MJ·m ⁻² ·a ⁻¹)	Number of occupants per building	Annual rate per occupant /(MJ·m ⁻² ·a ⁻¹)
	Initial	Repair & Maintenance	Operational	Demolition and decommissioning				
Housing authority standard block 50 years	6058	8052	17733	56	31899	709	3196	0.22
Private sector standard block 50 years	8708	12128	12836	83	33755	750	645	1.16
Integer concept tower 50 years	8619	12128	13407	56	32364	719	594	1.21
Integer concept tower 75 years	8619	15423	18187	56	42285	563	594	0.95

Table 2. Waste volume figures for various life cycle stages.

Environmental indicator category	Waste volume in stages /(dm ³ /m ²)				Mass of total life cycle waste /(t/m ²)	Annual waste rate/(dm ³ ·m ⁻² ·a ⁻¹)	Number of occupants per building	Annual rate per occupant /(dm ³ ·m ⁻² ·a ⁻¹)
	Landfill initial	Landfill deconstruction	Recycled	Total Life Cycle Waste				
Housing authority standard block 50 years	38.00	899.80	17.87	920	34361	20.84	3196	0.007
Private sector standard block 50 years	29.24	1022.47	28.14	1024	20088	23.37	645	0.036
Integer concept tower 50 years	18.04	857.43	42.15	833	22548	19.45	594	0.033
Integer concept tower 75 years	18.04	857.43	42.15	833	22548	12.51	594	0.021

Table 3. Quantities of CO₂ at various life cycle stages

Environmental indicator category	CO ₂ mass / (kg/m ²)				CO ₂ mass of total life cycle /(kg/m ²)	Annual CO ₂ mass /(kg·m ⁻² ·a ⁻¹)	Number of occupants per building	Annual rate per occupant /(kg·m ⁻² ·a ⁻¹)
	Initial	Repair & Maintenance	Operational	Demolition and decommissioning				
Housing authority standard block 50 years	987	2131	2963	*	6082	135	3196	0.04
Private sector standard block 50 years	1527	2245	2145	*	5918	132	645	0.20
Integer concept tower 50 years	1522	2044	2241	*	5808	129	594	0.22
Integer concept tower 75 years	1633	3066	3361	*	8060	107	594	0.18

Table 4. Cost figures for various life cycle stages.

Economic indicator category	Cost (\$/m ²)					Whole Life Costs /(\$/m ²)	Annual cost rate /(\$·m ⁻² ·a ⁻¹)	Number of occupants per building	Annual rate per occupant /(kg·m ⁻² ·a ⁻¹)
	Capital	Repair & Maintenance	Operational (management)	Operational (energy)	Demolition and decommissioning				
Housing authority standard block 50 years	5354	4185	2835	6545	47	18965	421	3196	0.13
Private sector standard block 50 years	8084	4859	5177	4525	90	22736	505	645	0.78
Integer concept tower 50 years	11083	4279	3837	4441	39	23678	526	594	0.89
Integer concept tower 75 years	10130	4490	5810	7350	60	27840	398	594	0.67

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.

- 1) 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.
- 2) 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.
- 3) 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.
- 4) The Integer Concept Tower is definitely worthy of further investigation.
- 5) 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.

- 1) The operational energy and CO₂ 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.
- 2) 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.
- 3) 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.
- 4) 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.

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