Whole Life Comparison of High Rise Residential Blocks in Hong Kong

Steven Humphrey
Davis Langdon & Seah Management Ltd.
Dr. Alexandre Amato & Professor Richard Frewer
University of Hong Kong, Department of Architecture
HKSAR

Introduction

This paper sets out the major findings and results of a detailed examination of the whole life construction cost and embodied environmental impact assessment for two typical concrete framed high-rise residential blocks constructed in Hong Kong. These blocks are the public rental 40 Storey Harmony 1 Block designed by the Hong Kong Housing Authority and a generic 40 Storey Private Sector concrete framed residential block. These types of residential block together account for a significant proportion of the recently constructed residential blocks in Hong Kong and therefore are considered to be highly representative of the Hong Kong construction market.

This study used and built upon previous work carried out by both Steven Humphrey [i] and Dr. Alex Amato [ii] into the whole life environmental and cost impact evaluation of concrete and steel framed buildings. This study is the first comprehensive examination of its type carried out in Hong Kong and by looking at public and private sector high-rise residential units produces results, which can be applied to a substantial segment of the Hong Kong construction market.

The whole life cycle methodology devised and adopted in this study has permitted for the first time a comprehensive comparison of the traditional Hong Kong construction technology, concrete framed structures, and most importantly allows the industry to critically examine where "hot spots" in terms of cost and environmental impact can be mitigated. This paper focuses primarily on the presentation of the detailed methodology adopted in the calculation of the life cycle costs, the results generated and their interpretation since other aspects of the methodology related to the LCA have been presented in previous papers [iii].

Methodology

The overall objective of this study has been to establish a robust methodology for the evaluation of buildings using Life Cycle Costing (LCC) and Life Cycle Assessment (LCA) techniques. This methodology, once in place, would allow the wider comparison of building designs in terms of their whole life economic and environmental profiles. The basic methodologies for LCC and LCA analysis are well documented [iv] but the level of detail applied in the usual assessment process, particularly in the case of LCC varies widely. The most commonly encountered problem with studying buildings using a combined LCC and LCA analysis is the fact that LCA by definition is a material based analysis, while LCC is most commonly used as a high level comparison tool where only total costs are presented. This means that typically a LCC analysis will simply present capital costs as a total figure and similarly for the recurring costs (operational, repair and maintenance costs) these too would be represented as an overall annual total. Although this fulfills the basic requirements of the published international standards and often the needs of the information user, it fails to provide information in enough detail or in a format which would allow professionals can make specific detailed design decisions. In view of this fundamental limitation with the direct comparison between LCC and LCA results, this study set out to carry out an analysis of typical multi-storey residential blocks using the same level of detail for both the LCC and LCA portions.

The core of the study was the detailed quantification of the buildings to be analyzed. The full environmental analysis of a building requires the quantification of all the different materials contained within the building in terms of their total mass. This mass information is then applied, in the case of this study, to 10 different environmental factors [v] to derive a series of environmental impacts. It is these impacts which allow the usage profiles of different materials within the building to be compared in the context of the whole block.

Whilst the quantification of the different materials within a building is essential for most comprehensive LCA methodologies it is unusual for LCC studies. Therefore, unlike other typical LCC assessments this study examined the opportunities for annotating all the materials used in the LCA calculation and then attributing to them their individual financial impacts. This meant that all the construction costs would have to be divided and allocated against each of the different materials within the building. This detailed splitting and allocation of the construction costs is made possible through the use of the bills of quantities prepared by the project quantity surveyors for these projects. These documents identify and quantify all the components within a building following a standard set of measurement rules [vi]. This standardization of measurement permits the individual items within a building to be further analyzed and sub-divided into the different material components. The benefit of using the bill of quantities as the basis for analysis is that it is this document which ultimately gets priced by the contractor executing the works on site, therefore the cost information generated can be directly linked back to the material quantity information.

Whilst the use of a bill of quantities is common for the initial construction (capital costs) of a project it is less frequently used for repair and maintenance works. In this instance alternative strategies had to be developed to address this information gap. It is usual, in Hong Kong as with elsewhere in the world, for maintenance works to be outsourced to private contractors. This outsourcing usually occurs on the basis of a set of term contract rates or on a cost reimbursable basis. The former method provides an opportunity for a fully price schedule of items to be in a similar format to a bill of quantity, although they do not usually follow the same strict measurement rules. Therefore it has been possible through the use of this financial information to quantify and attribute costs to different maintenance activities while at the same time generating some detailed material quantities. In practice this has meant that for most maintenance activities it has been possible to quantify the amount of material consumed when performing a particular maintenance operation. This information can then be used in the LCA evaluation as well as the LCC calculations. The only aspect that has not been fully accounted for by adopting this approach was the actual frequency of each individual maintenance operation.

The frequency of each maintenance operation can be established in a number of ways, as stated in ISO 15686, the optimum approaches are to use historical records or a factored approach. Clearly it is often impossible to obtain accurate historical records either due to a building never having been constructed or because owners have not specifically recorded the necessary information. In addition limited published information often exists which clearly sets out recommended or actual maintenance frequencies or life expectancies of different construction materials or systems. One of the few authoritative publications is the Life Expectancy of Building Components [vii]. This publication records the experiences in the UK construction market on service lives of different building materials and components, which whilst based upon the UK market provides a guide for users elsewhere in the world where similar information does not exist.

In this study detailed historical information for certain maintenance tasks were made available from a number of sources, including the Property Services and District Term Contracts of the Hong Kong Housing Authority. Through the analysis of the data from these different sources consistencies and trends were identified from which it was possible to produce a detailed maintenance profile for the typical Housing Authority block which was supported to a large extent by factual historical data. A similar approach was adopted for the typical private sector block, with the results generated being verified by making reference to building management annual reports and accounts for selected private sector developments.

All of the above data sourcing performed clearly demonstrated the need for better local historical maintenance information. However, through the development of this assessment methodology and the computer model produced it is possible for future clients to introduce their own actual historical maintenance data into the calculation process. This actual data would override the default values providing more representative and client focused results. This personalization also means that different client policies and approaches can be reflected in the results and equally the impact of different building occupant profiles can be assessed in greater detail.

The methodology presented above whilst being consistent with international standards, is also simple enough to permit a wider application on other building types both in Hong Kong and around the world. This point is important since the long-term objective of this study will be to provide a widely available computer based model which permits the analysis and review of any building type with a view to enhancing its whole life cost and environmental profile.

Results

Applying the above methodology to a 40 Storey Harmony 1 Block constructed by the Hong Kong Housing Authority and a typical 40 Storey Private Sector residential block, the whole life cost results generated were as set out in Figure 1 below.

These results demonstrate that whilst capital construction costs are a significant proportion of the whole life cost (28% for Housing Block and 36% for Private Sector Block) the recurring costs are also very substantial. This finding, whilst relatively obvious represents a more important consideration in the context of sustainability, in that the longer the building is owned and operated the greater the proportion of the whole life cost which will be attributed to the recurring annual costs. Hence as buildings today are being designed for longer lives it is critical that greater emphasis and importance is placed on mitigating recurring costs.

Economic Category	**Housing Authority Block** *Based upon 50 year life*	**Private Sector Block** *Based upon 50 year life*
Capital Cost	HK$5,354 / m2 CFA	HK$8,084 /m2 CFA
Repair and Maintenance Cost	HK$4,185 / m2 CFA	HK$4,859 / m2 CFA
Operational Costs (Management)	HK$2,835 / m2 CFA	HK$5,177 / m2 CFA
Operational Costs (Utilities)	HK$6,545 / m2 CFA	HK$4,525 /m2 CFA
End of Life Cost (Demolition)	HK$47 / m2 CFA	HK$90 / m2 CFA
Whole Life Cost	**HK$18,965 / m2 CFA**	**HK$22,736 / m2 CFA**

Figure 1 - Whole Life Cost Profile of Studied Blocks

When the above results are analyzed in greater detail it is clear that operational energy costs are higher in the Housing Authority block when compared with the Private Sector block, this is primarily due to the greater population density (approximately 3,200 people in the Housing Authority block compared with 650 people in the Private Sector Block). Coupled with this is the fact that the Housing Authority block is designed and built as public rental housing, as such many of the tenants tend to spend a larger proportion of their time within the flat units, whereas in a typical Private Sector block a higher proportion of the residents would be out at work during the day. These factors both contribute to the proportionally higher electricity consumption patterns found in the Housing Authority block.

The converse situation is found in the case of the management costs, where the larger scale of the Housing Authority block means that the costs actually incurred, whilst similar to the Private Sector block in total cost terms, are apportioned over a larger building area (approximately 52% larger) which results in a lower cost per floor area.

Whilst the Housing Authority block is public housing and therefore has to be designed to be both economical and functional the above results show that despite the potential for a high recurring maintenance cost due to larger population churn rates, historical data shows that following a strategy of providing economical yet durable materials it has been possible to maintain buildings economically. The Private Sector by contrast has a higher recurring cost due to the generally higher standard of materials used within the building initially. Although it should be noted that the Private Sector block relies heavily on the external image to attract future occupiers, hence visual appearance is important.

In addition, the above analysis does not account for the costs associated with occupant fitting out works, which in the case of the Private Sector block are likely to be significantly higher than the Housing Authority block, due to the social status of the occupants. The implication of this point would be that the gap between the two building types will be greater, in financial terms, than shown above.

In the case of the environmental impact results, the general overall trend for all the different impacts can be illustrated using the results from the Embodied Energy results, which are set out in Figure 2.

Environmental Category	**Housing Authority Block** *Based upon 50 year life*	**Private Sector Block** *Based upon 50 year life*
Initial Impact	6,058MJ / m2 CFA	8,708 MJ /m2 CFA
Repair and Maintenance Impact	8,052 MJ / m2 CFA	12,128 MJ / m2 CFA
Operational Energy Impact	17,733 MJ / m2 CFA	12,836 MJ /m2 CFA
End of Life Impact	56 MJ / m2 CFA	83 MJ / m2 CFA
Whole Life Impact	**31,899 MJ / m2 CFA**	**33,755 MJ / m2 CFA**

Figure 2 - Whole Life Embodied Energy Profile of Studied Blocks

The above results clearly illustrate that the higher electricity consumption identified in the cost analysis are the primary driver behind the greater operational energy impact generated. It is however important to note that in all the environmental impact results (except operational energy), one of the key determining factors in all cases was the total mass of the different materials used during the life of the building. Although the frequency or quantity of each material used is the most important determinant in the environmental analysis, the physical mass of the material also dictates the ultimate environmental impact. Therefore when the material consumption within a building is analyzed in detail it can be seen that those materials with the largest quantity and density dominate the list of high impact materials.

In the context of the studied blocks and Hong Kong in general, the environmental impact results are dominated by concrete, steel reinforcement and timber formwork primarily because the structural frame of the building is reinforced concrete. At a more detailed level, those materials which have a frequent recurring maintenance profile, such as timber doors, floor tiling and roof waterproofing are also items which have a high environmental impact over the whole life of the building. Based upon the results in Figure 2 above, the lower maintenance impacts for the Housing Authority block reflects the nature of the materials used rather than any specific enhanced maintenance or material performance.

All of these conclusions and results highlight the need for careful examination of initial design decisions. Since environmental impacts generally follow consumption patterns those materials which have the greatest whole life usage must be examined to see if reduction opportunities exist, either through alternative design solutions or different maintenance strategies. The use of the developed methodology permits these alternative proposals to be examined not simply against their potential environmental impact but also against the long-term economic implications as well. It is hoped that through the results generated more informed decisions can be made which will aid the optimization of both these competing objectives.

Implications

The results and methodology presented above are by themselves useful, but the true potential of this approach will be in the application of this methodology to identify materials or components within buildings which could potentially be enhanced so as to lower the overall whole life cost. In this respect the Housing Authority has identified this potential opportunity and initiated a study to examine the LCC / LCA of different building materials and components within their standard block design. This study will begin the process of analyzing cost and environmental “hot spots” within current building designs and then explore opportunities for substitutions which offer better potential long term value. The intention of this study and future research will be to identify design opportunities for clients which do not diminish the quality of a building but provide a more sustainable outcome.

This study and the results presented are intended to begin to address and quantify the question of sustainability in the Hong Kong construction market. Since residential developments in Hong Kong dominate the construction market, with the Housing Authority as the largest property owner, decisions made at the initial construction stage have long-term implications on society. The results above demonstrate that the Housing Authority blocks perform well in comparison with other typical residential blocks in the local market, but there are always opportunities for improvement. The methodology developed is designed to facilitate the identification of these areas, but equally the methodology should not be limited to applications on public housing blocks. The approach and produced models are equally applicable to all types of developments in both the public and private sectors.

Summary

In summary therefore, the LCC methodology devised for this study and set out above, follows the established rules for LCC assessments, but instead of simply considering costs at the highest level (total cost), this analysis has sub-divided each cost category into the different individual rates which in turn permits pricing and quantity relationships to be created for each material, component or system being used within the building. It has been this detailed examination which enables a direct link to be created between LCA impacts and LCC costs. The importance of this link is that when changes are made to different systems or materials, not only can the environmental impacts be clearly identified but also the whole life cost implications. The research to date has demonstrated that some design decisions which have been made solely on the basis of the best LCA results can have the opposite effect when the LCC results are analyzed. This is important since it highlights the need for sustainability to be a balance between a number of competing objectives.

Conclusion

This research study is the second stage of a long-term research project aimed at providing whole life profile information for designers and clients throughout Hong Kong. The ultimate objective is to provide a decision making tool for key stakeholders when they consider investment and design decisions. The results generated to date provide the opportunity for residential building developers who have large building portfolios, such as the Hong Kong Housing Authority, to identify areas of potential concern in terms of high environmental impact or significant recurring economic implications, then armed with this information they can formulate strategies which specifically target these areas.

It should be noted that whilst building benchmarking is possible and provides valuable information to clients the objective of this methodology is not to create an assessment tool for ranking or grading different buildings. There are numerous tools [viii] and methodologies available, both in Hong Kong and around the world which fulfill this task, the objective of this methodology is to help decision makers choose between competing design solutions as well as identify opportunities for improvement.

In the context of the Hong Kong Housing Authority as a significant landlord in Hong Kong this methodology provides for the first time the opportunity to critically analyze the performance of different estates and blocks within an estate to identify trends but more importantly problem areas. When more detailed historical operation and maintenance data is introduced into the model it would be possible, potentially, to see whether social or occupant variances impact on the whole life economic profile of different estates. In addition, where certain materials or systems within a block or estate are subjected to repeated maintenance or replacement, alternative systems can be analyzed to identify opportunities for improvement without any consequential impact on the environment. All of this means that long term economic benefits can be realized through lowering recurring cost which as capital investment becomes tighter will dominate annual expenditure profiles.

As this long-term study continues more results and analysis will be published to aid the understanding and appreciation of the relationship between LCC and LCA results in the context of construction sustainability.

References

i HKUST & Davis Langdon and Seah Hong Kong Ltd., :- **Cost Efficiency of Structural Designs of Standard Domestic Blocks** Presented to the Hong Kong Housing Authority, July 1999

ii Amato, A :- **A Comparative Environmental Appraisal of Alternative Framing Systems for Offices** Published by Oxford Brooks University UK, July 1996

iii Amato, A, Frewer, R, Humphrey, S,:- **A Comparative Sustainability Assessment of Steel and Concrete Framed Housing Blocks in Hong Kong**, Presented at CITC-II Conference, Hong Kong, December 2003

iv Related international standards are; LCC methodology **ASTM E-917-99 (USA), AS/NZS 4536:1999 (Australia / New Zealand) and ISO 15686** while for the LCA methodology **ISO 14040** and Howard, N, Edwards, S, and Anderson, J, **BRE Methodology for Environmental Profiles of Construction Materials, Components and Buildings**, published by BRE, UK, 1999, refer.

v Energy, Resource Depletion, Water Consumption, Waste, Climate Change, Acid Rain, Photochemical Smog, Ozone Depletion, Toxicity to Humans and Toxicity to Ecosystems.

vi **Hong Kong Standard Method of Measurement for Building Works**, Published by the Joint Standing Committee of the Hong Kong Institute of Surveyors, 1979 Third Edition, Hong Kong

vii **Life Expectancy of Building Components 2001 Edition**, BCIS / BMI Publications, UK

viii **HK-BEAM** (HK-BEAM Society, Hong Kong), **US-LEED (**US Green Building Counsel) and **BREEAM** (Building Research Establishment in UK) are three examples of "environmental assessment tools" available and adopted in Hong Kong.

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