profile. In the case of the operational costs of the building, these have been generated from historical consumption records from different clients and information on utility pricing in the public domain. The other key operational cost included within the overall whole-life assessment has been the administration and management costs for the different building types. Here actual records for selected buildings have been examined and since Hong Kong generally adopts an outsourcing model the identification of these costs, from the housing authority's property services contracts and private sector building management companies, is relatively easy. The inclusion of this information is considered necessary to ensure that the true whole-life cost of the building is presented and allows future comparative analysis to be made and placed in the context of the whole-building cost and not just a segment of the building cost profile.

All of the indicators selected for measurement in this study are capable of division into the different stages of the building life, namely initial, repair and maintenance, and end of life. In the case of the operational stage, the only indicator not measured here is waste. The models created in this study allow complete life profiles for each of the indicators measured to be presented in numerical and graphical form, and together produce a detailed inventory of the building throughout its whole life.

Comparative analysis

Having derived models and subsequent data, a series of comparative analyses were carried out including an overall embodied life-cycle analysis, an analysis of operational energy, and construction costs.

An overall embodied life-cycle comparison (omitting operational energy/CO_2) was carried out on the selected building types. Assessments were made at key points during the buildings' life cycles and differences that emerged were analysed on an element-by-element basis. There will be further careful scrutiny of the different repair and refurbishment regimes to ascertain if they lead to any expected difference in the notional building life of each housing type. The sensitivity of this data will be examined to determine whether the quality of the data will influence the overall results. This is considered to be important since all of the building types being studied are less than their planned design lives, making historical information for older

building unavailable. Clearly if the repair and maintenance data is sensitive in the overall model, then the impact of variations in the regimes adopted in older buildings may have an impact on the overall whole-life assessment results.

Operational energy/CO_2 was also assessed and although differences emerged between the two existing housing types due to the varying occupant lifestyles, a breakdown of the data indicates areas where comparisons in construction material usage are valid. However, the main purpose for the inclusion of operational energy/CO_2 is to set the embodied impacts and capital cost in the context of the block as a whole. This is important in discovering the best ways of reducing the environmental impacts of constructing and operating for all the housing types. Moreover, attempts to reduce operational impacts are often dependent on changing or improving the building construction in some way (e.g. additional insulation). Construction methods almost certainly have an impact on the cost and embodied energy/CO_2 content of the building; usually (but not always) increasing them. A cost–benefit assessment of each suggested 'improvement' will therefore be undertaken to ensure that it is worthwhile both in terms of environmental benefit and capital cost.

Construction waste produced by each building type was compared in the construction phase, in the repair and refurbishment regime, and in the demolition phase. During these phases, specific detailed analysis was carried out using three assumptions that:

1. **no materials are recovered for recycling/reuse**
2. **easily recoverable or valuable materials are recovered for recycling and/or reuse**
3. **all possible recyclable and/or reusable materials are recovered for recycling and reuse**

Development of improvement strategies

From the detailed analysis carried out above, it should become evident where improvements can be made. For example, if the life-cycle energy and CO_2 impacts are found to dominate the operational phase and especially in the growth of air-conditioning, strategies will focus on improving fabric insulation, renewable energy sources like photovoltaic cladding, passive