A Holistic Strategy to Extend Service Life of Aged Buildings

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ABSTRACT

Hong Kong is a crowded city with over seven million people living in an area of 1100km². The Hong Kong Housing Authority (HKHA) is the major government institution responsible for constructing public housing as well as maintaining its housing stock of 730,000 units. The public housing is now home for over 2 million people since its first development 60 years ago. With an increasing number of public rental housing buildings approaching 40 years old, the HKHA is facing a major challenge in sustaining its aged housing stock to meet the needs of tenants with heightened expectations.

In 2005/06, the HKHA launched a holistic strategy, embracing the Total Maintenance Scheme (TMS), the Comprehensive Structural Investigation Programme (CSIP), and the Estate Improvement Programme (EIP) with the purpose of enhancing sustainability of its buildings using pro-active, systematic and customer-oriented approaches. The TMS features proactive in-flat inspection in five-year cycles, prompt repair and education for tenants to prevent minor repair issues from blowing up into major problems. The CSIP aims to identify the root causes of structural defects, examines the vulnerability of structural elements, and forecasts the long-term structural health of aged buildings. Based on the investigation results, tailor-designed repair solutions are established to extend the service life of aged buildings for at least 15 years. Following the CSIP for an estate, an EIP is implemented to execute the proposed structural repairs together with facility improvements to address demographic changes and growing demands of the estate community. Indeed, the holistic strategy since its inception has been proven to be a success in extending the service life of aged buildings while meeting the sustainability challenges on environmental, economical, and social fronts.

Keywords: Building Service Life; Building Sustainability; Total Maintenance Scheme (TMS); Comprehensive Structural Investigation (CSIP); Estate Improvement Programme (EIP).

1. BUILDING SUSTAINABILITY

Sustainability is the ability to meet today’s needs without compromising those of subsequent generations. For the past decade, a high level of research interest in green buildings has spawned notable environmental advances on all fronts including design philosophy, construction methodology, and energy efficiency. Many of the advances have been put into practice today by the building industry resulting in innovative buildings with lower carbon footprints and enhanced sustainability. While the industry is heading in the right direction, building sustainability cannot be truly achieved without a holistic strategy in extending the service life of existing buildings. In fact, in a highly developed city like Hong Kong, the number of newly completed residential flats in 2012 was only 19,900 units, which represents less than 1% of the 2.6 million residential flats of all types in Hong Kong (Census and Statistics Department, 2013). Even under an aggressive public rental housing (PRH) production plan, the target production of the Hong Kong Housing Authority (HKHA) is about 79,000 flats from 2012/13 to 2016/17, which corresponds to only about one-tenth of the existing...
2. SERVICE LIFE OF PRH BUILDINGS

The overall service life of a building is characterized by the time limit at which the required operating qualities can be adequately served by the building. The time limit is governed by the lesser of the physical or obsolescent service life. For a PRH building, physical service life ends when the building degrades to a point when its structural integrity is no longer economically viable to maintain. On the other hand, obsolescent service life for a PRH building is defined by the time when the building ceases to meet the living needs of tenants.

2.1 CHALLENGES IN PHYSICAL SERVICE LIFE

Public housing in Hong Kong has a long history tracing back to the early 1950s. Today, the HKHA is managing 1,170 buildings in which 18% were constructed in or before the 1970s and 44% were constructed in or before the 1980s. Notwithstanding a series of comprehensive maintenance programmes, aging is still the single most important factor in the structural deterioration of PRH buildings. Besides the normal aging process, other macro and micro environmental factors play a significant role in the physical service life of PRH buildings. In terms of macro environmental factors, Hong Kong is a hot and humid coastal city. Effects of the coastal environment, high temperature, high humidity, and acid rain all increase the risk and rate of steel corrosion. In terms of local factors, problems in early design result in low maintainability and high susceptibility to environmental attacks. As the maintenance needs for many of these early PRH buildings became unsustainable, a massive redevelopment programme was initiated in the 1970s in order to completely redevelop these buildings. Considering the significant environmental impacts of complete redevelopment, the HKHA is now proactively addressing the root problems of structural deterioration in prolonging the physical service life of its aging housing stock with new techniques and solutions.

2.2 CHALLENGES AGAINST OBsolescence

As important as the physical condition of PRH buildings, their built environment and facilities must be well kept to meet the rising expectations and changing needs of tenants. Certainly, the tenants’ expectations in the 1950s for the early seven storey walk-up blocks in Shek Kip Mei Estate were very different from the tenants’ expectations in a PRH estate today. Long gone was the time when tenants shared communal toilets and cooked in public corridors. With improved social and economical conditions in the 1970s, these early design soon became obsolete and undesirable in Hong Kong. The massive redevelopment programme undertaken since the 1970s replaced these older blocks with self-contained units each equipped with an in-flat kitchen, a bathroom and a balcony. Space allocation, ventilation design and daylight penetration have all been enhanced to meet the demand for a better quality of life. However, with a low birth rate and longer life expectancy in Hong Kong, the tenant age profile is changing gradually. With an elderly population of 23% in the PRH community
today, the HKHA once again is required to reinvent its PRH estates so that the built environment and facilities would address the tenants’ needs at every stage of their lives.

3. THE HOLISTIC STRATEGY FOR BUILDING SERVICE LIFE EXTENSION

A holistic strategy for building service life extension is a comprehensive strategy that addresses the physical and obsolescent challenges in building service life. To extend the service life of aged PRH buildings, the HKHA adopts a holistic strategy that includes three key initiatives: TMS, CSIP and EIP, which together satisfy the three broad principles (Figure 1) of sustainability as follows:

![HKHA's Holistic Strategy](image.png)

**Figure 1: HAHK’s Holistic Strategy in Building Sustainability: TMS, CSIP, EIP**

### 3.1 TOTAL MAINTENANCE SCHEME (TMS)

The HKHA adopts a cyclic maintenance strategy in taking care of its housing stock. With the heart of providing quality housing to low-income families in a sustainable manner, planning of maintenance commences at the design stage of a new building. Selection of materials and installation methods are carried out with due consideration of future maintenance needs. Implementation of planned and routine maintenance of PRH blocks is initiated once a new building is completed. In taking a bold step forward, the HKHA launched the TMS in 2006, which is a comprehensive, proactive and customer-oriented programme for tenants in a bid to prevent minor repair issues from blowing up into major problems. The TMS adopts a three-pronged approach in the delivery of maintenance services in five-year cycles, namely, (i) proactive identification of maintenance problems, (ii) prompt response to tenants’ requests for repairs and (iii) enhanced publicity and education to tenants. Rather than reacting to complaints or requests for repairs, in-flat inspection ambassadors trained under the TMS visit individual households and carry out in-flat condition surveys. With a computerized system developed to support the TMS, inspection findings are recorded on personal digital assistants (PDAs). On-the-spot repairs are carried out for minor defects while
works orders are issued with PDAs for prompt rectification of more complex problems. To strengthen communication with tenants, a maintenance hotline supported by a call centre has been set up to handle calls concerning inspection appointments, complaints and enquiries. Regular reports are generated by the computerized system to facilitate monitoring of appointments and repair services. With the computerized system storing inspection survey results and repair records, a comprehensive database has been developed facilitating traceability and in-depth analysis for review of future maintenance strategy.

Making good use of in-flat inspection opportunity, TMS ambassadors also educate tenants on the proper use and maintenance of the fittings and facilities provided in their flats. To cultivate a customer-oriented service culture, seminars and workshops for experience sharing to maintenance contractors are arranged. Regular meetings are also held with the Estate Management Advisory Committees, District Council members and tenants to report work progress and collect feedback. To promote awareness and values of the TMS, a Maintenance Education Centre and various Mobile Maintenance Education Booths are set up for tenants with display boards, videos corners and mock-up demonstrations of building components. Promotional videos of proper home maintenance featuring celebrity icons are also broadcast at prominent estate areas.

The TMS is a successful maintenance strategy that addresses environmental, economical, and social aspects of sustainability. Environmentally, there are benefits in terms of enhanced physical service life while minimizing major repairs. Economically, the life-cycle repair cost can be reduced by proactively identifying and eliminating minor problems from blowing into major issues. Furthermore, the real on-going TMS cost is anticipated to be lower in the next 5-year cycle as most of the problems would have been addressed in the first time. Socially, with timely rectification of defects, tenants can enjoy a better living environment, which has been proven by a tenant satisfaction rate of over 80% since the launch of the TMS.

3.2 Comprehensive Structural Investigation Programme (CSIP)

Launched in 2005, the CSIP is implemented for estates approaching 40 years of age and at a 15-year interval afterwards. The CSIP systematically and thoroughly probes into structural conditions of aged PRH buildings and determines whether they are structurally safe and economically viable to maintain. Based on the Comprehensive Structural Investigation (CSI) results, tailor-designed repair solutions are established to extend the service life of aged buildings for at least 15 years. Previous findings revealed that deterioration to buildings in these estates varies significantly in both extent and severity. While visible defects of older buildings usually draw the most attention, there were cases of visually sound members in younger buildings concealing an advanced level of rebar corrosion. As a result, a timely CSI coupled with a tailor-designed repair strategy are crucial for the physical service life extension of PRH buildings. The six major steps for a typical CSI are described below:

i) Desktop Study

A desktop study for a new CSI involves the study of records including repair history, record drawings, design calculations, past structural appraisals, and previous improvement/strengthening records. Elements that previously required substantial or repeated repairs are one of the main focus areas in the new investigation.

ii) Visual Survey
A visual survey is conducted to cover all common and external areas. However, visual inspections to occupied flats could be considered as nuisance by some tenants. As a result, a representative sampling approach (e.g. a 5% inspection rate for occupied flats) is necessary to balance accuracy with the level of disturbance. Where the level of deterioration varies significantly due to differences in workmanship, usage and performance, a higher inspection rate is used to gain a deeper insight into the deterioration extent and severity. Repair records are retrieved and tenants are also interviewed in order to obtain a better picture on the history of defects and repairs. Besides documenting all visible defects on structural elements, the aim of a visual survey is also to identify symptoms and clues which would characterize underlying structural degradation processes.

**iii) Testing**

Based on the information gathered from the desktop study and visual survey, a test programme is devised in order to diagnose the in-depth conditions of structural elements and confirm the root causes of defects. Destructive tests include rebar corrosion measurements, concrete core compression tests, carbonation depth measurements, and chloride content analysis. To minimize disturbance to tenants, destructive tests are mainly conducted in common areas and vacant flats only. On the other hand, non-destructive tests are carried out at common areas, vacant flats, as well as in occupied flats. These tests include concrete moisture content measurements to locate the source of water seepage; concrete void detections to examine delamination and spalling; half cell potential tests to assess corrosion risks; and corrosion current surveys to quantify reinforcement corrosion rates.

**iv) Physical Service Life Assessment**

Adopting the concept of a “reversible limit state” as defined in EN 1990:2002 (BSI 2002), a structural defect is considered to be an acceptable defect when it can be repaired economically and “reversed” if appropriate action is taken. On the other hand, a building with structural defects that cannot be economically restored or repaired is considered to be beyond the ‘reversible limit state’ and would represent the end of its physical service life. As a result, the aim of a CSIP physical service life assessment is to facilitate the development of a repair scheme that is effective in extending the service life of an aged building in a sustainable manner as illustrated in Figure 2.

![Figure 2: Physical Service Life Extension of PRH Buildings](image-url)
With sufficient data collected from a well devised testing programme, a physical service life assessment could be carried out as follows:

- Appraise the residual capacity of various structural elements and assess structural stability based on current structural conditions;
- Evaluate the severity, extent and nature of deteriorations. Establish the causes and mechanisms of deteriorations and assess factors which could have significant effects on the degradation process such as concrete cover depths, screeding thicknesses and material strengths;
- Estimate future deterioration rates for various groups of structural elements based on condition survey data, existing chloride contents, carbonation depths, and current corrosion rates. Particular attention should be given to the effects of various repair schemes on future deterioration rates.
- Assess structural stability and appraise the residual capacity of structural elements with proper maintenance.

Based on the CSIP experience, vertical structural elements typically govern the building residual service life as the restoration cost on walls and columns extensively deteriorated is prohibitively high. As a result, using the predicted corrosion rates for vertical elements, the likely residual period of time before steel corrosion reaching the minimum acceptable level can then be predicted at 90% probability. An example of the residual physical service life modeling result for a building maintained under the holistic strategy of the HKHA is illustrated in Figure 3.

![Figure 3: An Illustrative Example of Physical Service Life Modeling for Building ‘E’](image)

v) Preventive and Repair Schemes for Physical Service life Extension

According to a survey done by the CONREPNET team (Matthews et al., 2007), only 50% of the structural repairs can be regarded as successful because of incorrect repair design, wrong diagnosis of root causes, underperformed repair materials, and poor workmanship. In fact, the remaining 50% were considered as successful in terms of works quality only. When the repair time and cost are considered, an even lower success rate is anticipated. As the holistic maintenance strategy of the HKHA is placing more and more emphasis on human and sustainability aspects, another key factor, which is as important as the cost, time and quality, in determining the final
success of a repair work is tenants’ perception. Tenants, as the receivers of service, may not understand the long term quality or cost of a repair. Rather, they care more about how a repair is handled, how disturbing (e.g. dust, noise, duration, frequency) is the repair, and whether workers are punctual and polite. Understanding the challenges of implementing a successful repair scheme, various sustainable and customer-oriented repair techniques have been adopted and developed under the CSIP as illustrated in Table 1:

<table>
<thead>
<tr>
<th>Repair Principles</th>
<th>Techniques Developed and Adopted under the CSIP</th>
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<tbody>
<tr>
<td>Protection against water ingress</td>
<td>- Anti-carbonation paint coating to delay carbonation and prevent corrosion</td>
</tr>
<tr>
<td></td>
<td>- Waterproofing with polyurea to stop water seepage without substrate demolition</td>
</tr>
<tr>
<td></td>
<td>- Multi-pulse sequencing system for stopping basement leakage</td>
</tr>
<tr>
<td>Structural restoration / strengthening</td>
<td>- Concrete restoration with high performance concrete (properties: low permeability, high workability, early strength gain, good compatibility with existing concrete)</td>
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<tr>
<td></td>
<td>- Stitching of movement joints to improve load carrying capacity</td>
</tr>
<tr>
<td></td>
<td>- Use of hydro-scarification for concrete/screeding demolition with minimal disturbance to tenants</td>
</tr>
<tr>
<td></td>
<td>- Use of galvanic sacrificial anodes to extend service life of repair</td>
</tr>
<tr>
<td>Improving micro-environment</td>
<td>- Converting façade grill-block walls into solid walls to eliminate water ponding problems</td>
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<tr>
<td></td>
<td>- Providing eaves as rain-shelter to reduce rain penetration</td>
</tr>
<tr>
<td></td>
<td>- Installing pipe plinths to stop water leakage at pipe piercing locations</td>
</tr>
<tr>
<td></td>
<td>- Removing non-structural elements prone to deterioration to reduce frequency of repairs</td>
</tr>
</tbody>
</table>

vi) Performance Monitoring

The CSIP is always about getting better by accumulating experience. In achieving this objective, long-term performance monitoring has been implemented to improve the future maintenance strategy. The monitoring includes visual surveys, moisture surveys, non-destructive tests, tenant interviews, and statistical analysis of maintenance requirements before and after repairs. Based on the monitoring results, adjustments and enhancements can be made to the formulated strategy with due considerations given to the environment, life-cycle cost, and disturbance to tenants.

3.3 Estate Improvement Programme (EIP)

With the physical service life being addressed by the CSIP, the obsolescent service life of an aged PRH estate is extended through the implementation of an estate-specific improvement programme, i.e. EIP. The aim of an EIP is to upgrade the provisions and facilities of an aged PRH estate so that it can continue to provide tenants with a decent living environment while meeting their up-to-date needs. Rather than taking a facility-based approach, a people-first and activity-based approach is adopted in the EIP design for better community bonding. During the conceptual stage, key concerns of a particular estate are identified through tenant surveys and EMAC consultation. Demography and unique estate features are studied and analyzed for a sustainable improvement scheme focusing on people. In particular, common areas and non-domestic premises are redesigned to suit tenants’ changing needs stemmed from the aging tenant profile. Recreational facilities (e.g. fitness equipment for the elderly) are enhanced to cater for different age groups and public space is reshaped to promote
social interaction. Weather-protected passage and barrier-free access such as new lifts and ramps are integrated into a master pedestrian network to improve pedestrian circulation with the needs of the elderly and disabled tenants in mind. External façades and public areas are face-lifted to provide a pleasant living environment while in-flat facilities such as grab rails are fixed inside bathrooms for elderly tenants. Environmental concepts are incorporated for greener and more energy-efficient designs. For instance, provision of green roofs on top of low-rise plant houses and non-domestic buildings can reduce indoor heat gain and at the same time improve the environment of a neighbourhood. Energy saving initiatives, such as energy-efficient corridor lighting are put in place. Aging building service installations are also gradually replaced and modernized with a comprehensive programme to lower the total life-cycle cost. Energy-efficient lifts are installed under the Lift Modernization Programme, which enable a reduction of energy cost by over 30% when compared to the existing ones. Indeed, by adopting a people-first and activity-based approach, the EIP is able to rejuvenate the community, forge stronger ties in the neighbourhood, and extend the obsolescent service life of PRH estates.

4. CONCLUSIONS

The HKHA is committed to provide affordable quality housing and maintenance to meet the needs and expectations of its tenants. With the aging of its tenants along with its housing stock, the HKHA is reinventing its aged estates through the three key initiatives: TMS, CSIP, and EIP. While the aim is to extend the physical and obsolescent service life of aging PRH buildings in a sustainable manner, HKHA’s holistic maintenance strategy is always centered on people. With the tenants at heart, all repairs and upgrades are customer-focused, addressing key concerns and needs of tenants while keeping disturbance and nuisance to a minimum. Indeed, the HKHA is proud to say that the holistic strategy is a success in extending the service life of aged buildings while meeting the sustainability challenges on environmental, economical, and social fronts.

5. REFERENCES

