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A survey of the health and safety conditions of apartment buildings in Hong Kong

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Abstract

A high-density built environment poses challenges to the idea of sustainable development in respect of health (e.g. SARS outbreak) and safety (e.g. fire and structural problems). To examine the seriousness of the high-density problem, this study aims to survey the health and safety performance of apartment buildings in a densely populated city, Hong Kong, using a simplified assessment scheme. An assessment scheme based on a hierarchy of building performance indicators concerning the quality of: (a) architectural design, (b) building services design, (c) the surrounding environment, (d) operations and maintenance, and (e) management approaches was developed. One hundred forty (140) apartment buildings were surveyed and assessed through site inspections, desk searches, and interviews. A performance analysis was conducted to examine and compare the overall health and safety performance of the buildings. We found that there were considerable variations in health and safety conditions across buildings, even though they are located within a single district. Most of the variations in building health and safety conditions were attributed to differences in building management systems rather than building design. Enhancing strategic management approaches (e.g. a better delineation of owners' rights and duties) appears to be the most critical factor that underperformers should consider in order to improve their buildings.

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1. Introduction

Hong Kong is one of the most densely populated cities in the world, with 6.7 million people living in an area of 1102 km². To accommodate this huge population in such a tiny place, a highly compact living environment characterized by high-rise apartment buildings has resulted. Recently, with the removal of airport height restrictions in urban areas, residential buildings have been built taller than ever before. It is very common to find new residential buildings that are over 50 storeys.1 While this gives Hong Kong a unique skyscraper identity, such a compact environment poses important questions for the concept of sustainability, in particular for the objective of promoting the social, economic, and environmental quality of human settlement development in Agenda 21 of the United Nations.

On the positive side, developing high-rise, high-density buildings is economically desirable because communal facilities and services can be shared more efficiently among co-owners or tenants. With regard to environmental protection, this can also help reduce urban sprawl and enhance land use efficiency. However, on the negative side, a high-density setting presents a serious threat to the health and safety status of residents. Gove et al. [1] showed that overcrowding has led not only to social incoherence, but

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1Here are some examples of high-rise residential developments in Hong Kong completed in recent years: Sorrento (75 storeys), Highcliff (72 storeys), the Harbourfront Landmark (70 storeys), the Summit (65 storeys), the Belcher’s (63 storeys), Victoria Towers (62 storeys), and Island Resort (60 storeys). More examples can be found on this website: (http://www.emporis.com).
also to mental and physical health problems. The outbreak of severe acute respiratory syndrome (SARS) in 2003 also made the public aware of the vulnerability of densely populated areas to communicable diseases [2]. Apart from health problems, older apartment buildings often lack proper building management and maintenance, possibly due to fragmented ownership and a lack of resources [3]. This poses tremendous safety hazards (e.g. fire and falling objects) to residents and passersby.

Since health and safety are among the most problematic issues in a high-density environment, this paper aims to survey the health and safety performance of apartment buildings in Hong Kong using a simplified assessment scheme. Health and safety were chosen as our focus because they are the most fundamental aspects that a dwelling should fulfill, and yet they usually cannot be easily observed and evaluated by occupants and the public. Moreover, health and safety problems have a stronger spillover effect in a high-density setting than a low-density one—a building with poor health and safety conditions not only adversely affects its own occupants, but also jeopardizes those living and working in the neighborhood. Our study, therefore, contributes to the revelation of hidden building information to the community, which, in turn, helps build a more sustainable city. Utilizing Ho et al.’s [5] simple assessment framework, we surveyed 140 buildings within a short period of time at a relatively low cost. We also extended Ho et al.’s [5] health assessment framework to building safety. To make the survey results more comprehensible to the public, we translated technical performance details into indices (e.g. a health index and a safety index) for building classification. With these indices, the public and building owners can easily know the health and safety performance of buildings.

The rest of the paper is organized as follows. Section 2 outlines our survey design and explains the assessment scheme. Section 3 describes the survey procedures, which include site inspections, desk searches, and interviews with management staff. The sampling strategy of 140 apartment buildings in Hong Kong is presented in Section 4. Section 5 reports the survey findings together with an attribution analysis of health and safety performance. Section 6 is the conclusion.

2. Survey design

2.1. Assessment principles

There are many ways to survey the condition of a building, ranging from the most costly method of laboratory tests to the simplest method of visual site inspection. The choice depends on the purpose and resources for assessment. Our purpose is to quickly scan the health and safety conditions of apartment buildings at the city level for building classification. Bearing this in mind, we based the principles of our survey design on the assessment model proposed by Ho et al. [5], which is simple, and yet theoretically sound. This assessment model is in line with the ideology of the assessment model developed by Kim et al. [8], which was designed not solely for state-of-the-art buildings, but also for existing buildings with various degrees of quality.

Our principles of survey design were laid down as follows. First, the items to be surveyed should be flexible enough to embrace most settings of private apartment buildings in a city (e.g. buildings of different designs). Second, for the sake of practicality, the items to be surveyed should be easily obtainable. Site inspections were confined to common areas and the external environment to where assessors could have access. These common areas are usually the most problematic in terms of management and maintenance due to the co-ownership nature of these areas [9]. As for the interior of individual dwelling units, the assessments were based largely on the information available in floor layout plans. Third, only measurable and verifiable items would be assessed, while subjective items should be avoided as much as possible. If subjective judgment (e.g. hygienic condition and visual structural condition) was unavoidable, assessors would be given clear guidelines, with judgments referenced to sample photos of different grades or scores to ensure consistency.

2.2. Defining health and safety

After laying down the principles and scopes of assessment, our next step was to define our objects of assessment—health and safety. We excluded factors not directly related to health and safety (e.g. energy efficiency and intelligence). A healthy building is one that minimizes the physical and mental health risk of its occupants, such as safeguarding against infectious diseases or chronic/mental illnesses found within the built environment. Ho et al. [5] pointed out some characteristics that a healthy building should have:

A healthy building should not be too densely populated; its window design and layout should facilitate natural ventilation and penetration of daylight; it should be isolated from noise and air pollution sources; its water supply and waste discharge systems should be properly

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2A discussion on the asymmetric information problem in the housing market can be found in Lützkendorf and Speer [4].

3This is analogous to Pavlov and Blazenko’s [6] argument that the proper maintenance of a property increases its neighborhood value.

4An outline of the assessment framework for building safety was given by Ho and Yau [7]. We further developed and refined their framework and converted it into a practical assessment scheme.

5The purpose of building classification is to classify buildings into different grades (e.g. Excellent, Fair, and Poor) according to certain predetermined objectives. This serves as a user-friendly indication of building performance for use by the general public.
installed, maintained, and managed; and its environmental conditions should be clean and hygienic (p. 62).

There was no similar definition for safety. Extending the health concept of Ho et al. [5], we defined a safe building as one that minimizes the risk of physical injury and the death of occupants, such as evacuating them effectively should emergencies arise. Hence, a safe building should have, *inter alia*, the following characteristics:

- a structurally sound construction design and condition;
- properly installed and maintained electrical and gas supply systems;
- a design that facilitates the evacuation of occupants in case of emergency; and
- a location that is less prone to flooding or landslides.

### 2.3. Assessment schemes

Based on the above criteria and the usual settings of private apartment buildings in Hong Kong, two assessment schemes, one for health (the Building Health and Hygiene Index, BHHI) and the other for safety (the Building Safety and Conditions Index, BSCI), were developed. The schemes are the realization and extension of the theoretical assessment framework laid down by Ho et al. [5]. Table 1 shows the building factors to be assessed and their relative weightings. There are 25 building factors for the BHHI and 19 building factors for the BSCI. To ease understanding and facilitate the performance attribution analysis, we structured the building factors (Level 3) into a hierarchy of performance indicators and grouped them under five main categories (Level 2):

1. **Architecture**: refers to the layout and elevation design of a building (e.g. plan shape, height, and disposition).
2. **Building services**: service components added onto a building’s fabric to provide functionality. Water supply, drainage, refuse disposal, fire services, electrical systems, etc. are included under this category.
3. **External environment**: the immediate external environment of a building can affect the health and safety of its occupants. For example, green parks are regarded as amenities, whereas street wet markets and petrol refill stations increase the health and safety hazards to a building.
4. **Operations and maintenance**: concerns operational issues in building management, which include the daily management tasks (e.g. cleaning and refuse disposal) and maintenance standards for a building.
5. **Management approaches**: are strategic issues in building management, which include the delineation of responsibility among owners, documentation, emergency preparedness, and the provision of feedback systems.

These five categories are further classified under two umbrellas (Level 1). On one hand, *architecture, building services, and external environment* are called design factors because they are unchangeable, or changeable only at a relatively high cost once a building has been built and in use. For example, it is usually difficult to add a sprinkler system at the occupancy stage because of insufficient space to accommodate the water tank and the distribution pipework, not to mention the high cost and disruptions involved. These factors should be dealt with in the design stage. On the other hand, *operations and maintenance and management approaches* are management factors because they are changeable in the occupancy stage, during which building management plays a very important role. For example, a contingency or sinking fund can be set up once building owners agree to do so.

The weightings of the building factors were assessed by two expert panels using Saaty’s [10] analytic hierarchy process (AHP). One panel was comprised of 35 experts in building health who gave their perceptions of the relative importance of the building factors in the BHHI scheme. The other panel was comprised of 23 experts in building safety who provided the weightings of the building factors in the BSCI scheme. Before starting the AHP interviews, the experts were given clear instructions on the pairwise comparison process and furnished with a definition of the key terms used in the questionnaires. All participants were allowed to ask questions to iron out any ambiguities. This procedure was indispensable, as respondents should have a common understanding of the questions before the results could be analyzed in a meaningful way. The respondents’ weightings of the different factors were extracted from a pairwise comparison of the relative importance of all pairs of factors at the same level as the hierarchy (as shown in Table 1) using the AHP computer package Expert Choice 2000, second edition. The detailed procedures of the interviews are shown in Fig. 1.

The AHP procedure for weighting determination is often deemed more reliable than direct weighting allocation because the former allows for the checking of internal consistencies in the answers from each respondent [10]. If inconsistencies were found, a respondent was allowed to revise his/her answers if s/he felt comfortable doing so. After this interactive interview process, if a respondent’s answers still failed to reach the consistency ratio suggested by Saaty, his/her responses would be discarded from the respective level in the hierarchy. Despite the high cost associated with this method of information collection, it greatly improved the reliability of the factor weightings, which is one of the most crucial aspects of the assessment framework. The weighting of each building factor was finally computed by averaging out the weightings obtained from the consistent responses.

To compute the rating of each building factor in the assessment scheme, one would normally use a continuous scale ranging from the best practice (rating = 1) to the worst practice (rating = 0). The worst practice is set with reference to the minimum standards required by trade
practice or law. The best practice is determined with reference to the highest standards available now or in the near future, including those recommended by the government, professional institutes, and relevant international guidelines. For example, while there is no statutory requirement for building owners in Hong Kong to carry out regular fire drills, the Fire Services Department and Home Affairs Department advise them to conduct fire drills at least once a year. Such a recommendation constitutes a best practice, the fulfillment of which will be rewarded with a rating of 1 in the respective building factor.

Table 1
Building factors assessed under the BHHI and BSCI, and their relative weightings

| Level 1 | Level 2 | Level 3 |
|---------|---------|---------|
| Weight (%) | Category | Weight (%) | Building factor | Weight (%) |
| **BHHI** | | | | |
| Design | 53.6 | Architecture | 18.5 | Size | 2.5 |
| | | | | Plan shape | 3.5 |
| | | | | Headroom | 2.0 |
| | | | | Windows | 5.7 |
| | | | | Noise reduction | 3.4 |
| | | | | Open space | 1.4 |
| | Building services | 19.3 | Water supply | 5.6 |
| | | | | Drainage | 6.8 |
| | | | | Refuse disposal | 4.7 |
| | | | | Lift | 2.2 |
| | External environment | 15.8 | Density | 1.9 |
| | | | | Adjacent use | 1.7 |
| | | | | Air quality | 5.2 |
| | | | | Aural quality | 2.6 |
| | | | | Visual obstruction | 1.6 |
| | | | | Thermal comfort | 2.8 |
| Management | 46.4 | Operations & maintenance | 27.1 | Cleaning | 5.1 |
| | | | | Pest control | 3.1 |
| | | | | Refuse handling | 4.6 |
| | | | | Drainage condition | 4.6 |
| | | | | Unauthorized alteration | 4.0 |
| | | | | Water quality | 5.7 |
| | Management approaches | 19.3 | Owners' duties | 7.9 |
| | | | | Documentation | 6.8 |
| | | | | Emergency preparedness | 4.6 |
| **BSCI** | | | | |
| Design | 47.0 | Architecture | 22.1 | Height and disposition | 3.8 |
| | | | | Means of escape | 9.3 |
| | | | | Means of access | 6.3 |
| | | | | Amenities | 2.7 |
| | Building services | 16.6 | Fire service installations | 8.3 |
| | | | | Electrical installations | 4.3 |
| | | | | Fuel supply | 4.0 |
| | External environment | 8.2 | Proximity to special hazards | 6.4 |
| | | | | Proximity to fire station | 1.8 |
| Management | 53.0 | Operations & maintenance | 33.5 | Structural condition | 8.6 |
| | | | | Building services condition | 5.3 |
| | | | | Exit routes condition | 8.4 |
| | | | | Fire compartmentation | 4.3 |
| | | | | Illegal appendages | 6.9 |
| | Management approaches | 19.5 | Owners' duties | 4.3 |
| | | | | Documentation | 3.5 |
| | | | | Emergency preparedness | 7.8 |
| | | | | Financial arrangement | 3.9 |
The rating of intermediate cases is made by linear interpolation. Take the headroom of a flat (a building factor under architecture) as an example. The rating is zero if headroom is below 2.5 m, which is the minimum required by the current regulation. Headroom above 3.1 m is the best scenario with a rating equal to one. For a headroom of 2.8 m, its rating is, by interpolation, 0.5.

When building factors are qualitative in nature, a different method is used to deal with intermediate cases. A dichotomous building factor (e.g. presence or absence of a certain design), by definition, has no intermediate case, and its rating is either zero or one. For multinomial building factor, we will describe clearly what each rating means, as illustrated in Table 2. If necessary, the written descriptions are accompanied by sample photos, so as to ensure that it is consistently understandable to all respondents.

### Table 2

| Grade       | Rating | Description                                           |
|-------------|--------|-------------------------------------------------------|
| Satisfactory| 1      | Good conditions without observable defects            |
| Above average | 0.75  | Surface of the pipe or brackets slightly rusted        |
| Acceptable  | 0.5    | Pipe partly rusted                                    |
| Deficient   | 0.25   | About half of the length of pipe rusted; vegetation growth around the pipe |
| Poor        | 0      | Choking and unsanitary conditions; whole length of the pipe seriously rusted; dripping observed, or pipe broken |

Fig. 1. A flowchart showing the procedures of the BHHI and BSCI workshops.

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Step 1: The background and objectives of the survey are first presented to the respondents.

Step 2: The respondents are given brief instructions on how to complete the questionnaire, followed by an explanation of the key terms used.

Step 3: The respondents fill in the questionnaire.

Step 4: The questionnaire results are keyed into a laptop computer while respondents take a break.

Step 5: The ranking, weighting, and internal consistency ratios are calculated by research assistants using the computer package Expert Choice 2000 2nd Edition.

Step 6: The analyzed results (i.e., the weighting and ranking of each attribute) are reported to respondents.

Step 7: If the internal consistency ratio at any level is not smaller than 0.1, the computer package will locate the possible sources of inconsistency. The respondent is allowed to revise his/her responses.

Step 8: The revision is keyed into a laptop computer. Instantaneous feedback on the internal consistency ratio is shown to each respondent.

Step 9: If the internal consistency ratio is still not lower than 0.1, the respondent can follow Steps 7 and 8 again for further revision. The process will continue until the respondent rejects making any further changes.
assessors. This arrangement makes judgments on both quantitative and qualitative criteria easier, and it works well even for inexperienced assessors [11].

3. Assessment procedures

The building survey was carried out by trained assessors. Before the assessments began, extensive training sessions were arranged to explain the assessment schemes. This helped standardize the data collection method, and hence increased efficiency and consistency. As the assessments progressed, moderation sessions were held to check for consistencies and to serve as a feedback mechanism for resolving any unexpected problems faced during data collection.

The assessment procedures can be divided into three major tasks:

3.1. Desk search

Most of the information required for design in Table 1 was acquired through desk searches. This included: (a) taking measurements from building layout plans, (b) searching for information on the web, and (c) analyzing street maps for items under external environment. The data collected from the desk searches is publicly available, and hence, is objective and verifiable.

A building plan study was conducted by the Buildings Department, into where the record plans of most postwar private buildings in Hong Kong are deposited. From the building layout plans, the assessors obtained information on a building’s design, such as its window-to-floor area ratio, the size of its residential units, and the widths of its staircases. In addition, the assessors were requested to visit the websites of government departments (to obtain information like the air pollution index) and web-based maps (for information like population density). Last, but not least, studying street maps obtained from the Survey and Mapping Office of the Lands Department can provide information for factors under external environment, such as the distance of a building from the nearest fire station and green space.

3.2. On-site assessment

Site visits are a necessary and essential part for verifying the actual health and safety conditions of a building. The need for site visits is demonstrable because the information from other sources does not often reflect the real situation of a building. Discrepancies between the situation on-site and the information contained in the official records or other sources are common [12]. An on-site assessment starts with an initial quick inspection of a building’s exterior prior to the internal inspection of the building. This sequence was justified by Hoxley [13], who stressed that anything missed during the initial inspection of the exterior could be re-inspected relatively easily, but it may not be so easy to re-inspect the interior when any problem is raised during the subsequent external inspection. The initial external inspection allows assessors to note the special areas or aspects to which they should pay more attention during the internal survey.

After entering a building, the assessors first went to its roof, which is a strategic location for inspecting certain parts of a building, such as its lightwells and re-entrants, which cannot be easily seen from other angles. The roof inspection was followed by a floor-by-floor survey starting with the top floor. The assessors had to inspect common areas like lift lobbies, corridors, and staircases on every residential floor. Non-intrusive tests, such as hammer tapping, were conducted to aid in the identification of defects during the course of inspection. After the internal building inspection, they walked around the building’s podium, if any, and surveyed the external façades of the building at safe and accessible positions. With the aid of binoculars, the assessors scanned through each building elevation carefully, covering every square metre. Finally, the commercial portion, external works, and surroundings of the building were evaluated, with particular attention being paid to the existence of special hazards to residents.

The whole survey lasted about 1–2 h, depending on the scale of development. Photographs had to be taken during the inspections for recording purposes. Also, any suspicious deficiency or irregularity spotted during the inspections had to be noted for later verification. All parameters to be measured or inspected on site were confined to: (a) common areas (e.g. podiums, lobbies, lifts, staircases, and corridors) where permission for access is given by owners or management agents, and (b) the surrounding external environment.

3.3. Structured interview

Inputs from owners’ organizations and/or property management companies were also required to evaluate their standards of management practice (e.g. inspection certificates for building services, planned maintenance schedules or policies, and monthly financial statements). With the use of a preset questionnaire, interviews with owners/management staff were conducted to collect this information. If necessary, the owner or management staff was requested to provide documentary records (e.g. tenant survey records and monthly financial statements) for verification. A sample of a questionnaire used is annexed in the appendix for illustration purposes.

4. Sample

There are about 38,000 multi-storey private buildings scattered all over Hong Kong [3]. In this survey, we

6Apart from binoculars, each assessor was equipped with a claw hammer, measuring tape, torches, and hand mirrors during the inspections.
shortlisted buildings from the Yau Ma Tei-Tsim Sha Tsui-Mongkok District (YTM), which is located on the southern part of the Kowloon Peninsula. The reasons for choosing YTM were twofold. First, building plans in YTM are more readily available than those in other districts due to the recent digitalization of the building plans by the government. Second, there is a wide variety of residential buildings in YTM (e.g. post-war traditional Chinese low-rise buildings, single block buildings in congested sites, buildings with very large footprint areas, and relatively new building developments). Such a wide range of building types, ages, and management structures enabled us to obtain a diversified sample to carry out further analysis.

The buildings in YTM were then stratified for random sampling. First, the whole district was divided into six zones (Prince Edward, Mong Kok, Tai Kok Tsui, Yau Ma Tei, Jordan, and Tsim Sha Tsui) according to their geographical locations. This ensured that our sampled buildings were spread around YTM with a minimal locational bias. Then, buildings were sampled from each zone according to development scale, building age, and management structure. This reduced potential bias towards a particular type of building. For housing estates that consist of multiple identical blocks of buildings, only one building from each estate was sampled for assessment because building performance within an estate should be very similar in terms of its design and management. Finally, all pre-war buildings (there are only a few left today) were excluded from the sample, since most of these buildings did not have building plan records.

Based on the above strategy, about 200 buildings were sampled, of which 140 buildings were assessed with complete information. Our discussion focuses only on these 140 buildings. As summarized in Table 3, the sample comprised buildings of varying physical characteristics, such as building age, flat size, and development scale. This wide coverage of building characteristics provided a good reference for other parts of Hong Kong in any future study.

5. Survey findings and performance analysis

5.1. Overall results

The raw data collected by the trained assessors was converted into a set of performance indicators that represent the health and safety conditions of each building factor in Table 1. The analysis of the assessment results will contribute to our understanding of the key factors that influence the variations in the health and safety performance of the apartment buildings.

To compute the overall health performance (BHHI) for building k, one simply needs to aggregate the ratings (Fik) and weightings (wik) of all n building factors:

\[ \text{BHHI}_k = \sum_{i=1}^{n} w_{ik} F_{ik}. \]  

Similarly, given the respective ratings (FSik) and weightings (WSik) for safety, the overall safety performance of building k is given by its BSCI:

\[ \text{BSCI}_k = \sum_{i=1}^{n} w_{Sik} F_{Sik}. \]

The subscripts H and S denote that a variable belongs to the health and safety equations, respectively. This notation is used throughout this paper.

The distributions of the BHHI and BSCI, after the application of Eqs. (1a) and (1b) to each building, are presented in Figs. 2 and 3, respectively. The median BHHI and BSCI scores were 44% and 56%, respectively. Specifically, the BHHI ranged from 24% to 60%, whereas the BSCI ranged from 35% to 74%. Since the indices are building-specific, the health/safety performance of one building can be compared to the others. A practical use of these results is to let stakeholders know whether a building outperforms or underperforms the median building in the sample. Homebuyers can use the information to ascertain how good a building performs before they make their decisions. It is likely that property values will be affected after the publication of the BHHI and BSCI. Building owners can also make use of the performance information to facilitate their maintenance or refurbishment decisions. In multi-ownership apartment buildings, one of the key obstacles in reaching collective decisions to carry out improvement works is that owners have different, if not conflicting, views on whether or not to make improvements. Sometimes, even though a building is obviously dilapidated, some owners may still not wish to face up to “reality” and commit to changes. If the BHHI and BSCI results indicated that the performance of their buildings lags behind that of similar buildings, their intolerant attitudes may change, as they do not want to be losers in the value league.

Table 3
Physical characteristics of the sampled buildings

| Characteristics     | Mean | Maximum | Minimum | Standard deviation |
|---------------------|------|---------|---------|--------------------|
| Age (year)          | 30.9 | 50      | 3       | 11.8               |
| Flat size (m²)      | 51.4 | 142.4   | 10.1    | 18.5               |
| No. of storeys      | 11.9 | 28      | 3       | 5.8                |
| No. of flats        | 55.9 | 420     | 3       | 69.4               |

7The weighted arithmetic mean was adopted to combine individual ratings into a single index because it is the most commonly used functional form for score aggregation in building performance assessment schemes. This form is predominately used in most of the pronounced schemes, such as the building research establishment environmental assessment method, the leadership in energy and environmental design and GBTool. Although So and Wong [14] counter-proposed using the weighted geometric mean for index aggregation, their viewpoints were not substantiated, neither theoretically nor empirically.

8Note that the BHHI and BSCI have different objectives (i.e., health and safety), so their scores should not be compared.
5.2. Performance attribution

As shown in Figs. 2 and 3, buildings differ, at most, by 36% for the BHHI and 40% for the BSCI. Why such a large difference? This is an important question for underperformers who want to catch up to others in the competition. A variance decomposition analysis was conducted to reveal the relative importance of the first level factors (design and management) in affecting the dispersion of the BHHI and BSCI.

By definition, the BHHI and BSCI are the weighted sums of the design index (DI) and the management index (MI), respectively.9 In other words:

\[
\text{BHHI}_k = w_{H,D} \text{DI}_{H,k} + w_{H,M} \text{MI}_{H,k},
\]

(2a)

\[
\text{BSCI}_k = w_{S,D} \text{DI}_{S,k} + w_{S,M} \text{MI}_{S,k},
\]

(2b)

The DI and the MI are performance indicators at Level 1. They were computed in a similar fashion as in Eqs. (1a) and (1b).
where $w_{j,D}$ and $w_{j,M}$ are the weights of design and management, respectively ($j = H$ or $S$). It follows that the total variation in the BHHI or BSCI is attributable to: (a) design variations, (b) management variations, and (c) their co-movements. We express their relationships as

\[
V(\text{BHHI}_k) = w_{H,D}^2 V(\text{DI}_{H,k}) + w_{H,M}^2 V(\text{MI}_{H,k}) + 2w_{H,DM} V(\text{DI}_{H,k}, \text{MI}_{H,k}), \quad (3a)
\]

\[
V(\text{BSCI}_k) = w_{S,D}^2 V(\text{DI}_{S,k}) + w_{S,M}^2 V(\text{MI}_{S,k}) + 2w_{S,DM} V(\text{DI}_{S,k}, \text{MI}_{S,k}), \quad (3b)
\]

where $V(\cdot)$ means variance and $\text{Cov}(\cdot)$ means covariance. Let $I_j$ be the total variance (i.e., $I_H = V(\text{BHHI}_k)$ and $I_S = V(\text{BSCI}_k)$). The relative importance of each component is given by:

- percentage of variations due purely to design factors $= w_{j,D}^2 V(\text{DI}_{j,k}) / I_j$;
- percentage of variations due purely to management factors $= w_{j,M}^2 V(\text{MI}_{j,k}) / I_j$; and
- percentage of variations due to their co-movements $= 2w_{j,DM} V(\text{DI}_{j,k}, \text{MI}_{j,k}) / I_j$.

Fig. 4 summarized the results in Venn diagrams. We see that 82% of variations in the BHHI are purely attributable to management factors, suggesting that management factors dominate design factors in differentiating healthy buildings from the relatively less healthy ones. Variations due to their co-movements were very low and insignificant, only 4%. For the BSCI, pure design factors contributed 18% to the total variation, while pure management factors contributed 45%. Similar to its health counterpart, pure management factors are more influential than pure design factors in affecting the variations in safety performance. In other words, most of the variations in building health and safety conditions were attributed to differences in building management rather than building design. This should be encouraging to owners of underperforming buildings because management factors are alterable during the occupancy stage, and they can improve health and safety performance by enhancing management. However, as opposed to the BHHI’s results, the co-movement of design and management factors occupies quite a significant share, being responsible for 37% of the variations in the BSCI. A possible reason for such a strong co-movement is that design and management factors are driven by some common factors, notably building age.\(^\text{10}\)

Further insight can be gained by looking at the results of Level 2 categories using radar diagrams, which allows for a performance comparison to be made for each category across different buildings. In Fig. 5, the best, average, and worst scenarios for architecture, building services, external environment, operations and maintenance, and management approaches are shown. The spread of performance in management approaches is the largest among all categorical scores for both the BHHI (from 0% to 100%) and BSCI (from 0% to 66%). This suggested that enhancing management approaches, such as delineating owners’ duties, implementing facility management practices, and enhancing the level of emergency preparedness, is the most critical item that underperformers should consider in order to improve their buildings. The differences in performance of other Level 2 categories can be observed similarly for the BHHI and BSCI, respectively. For instance, there are also considerable spreads in the performance of building services (2–67% for the BHHI; 26–80% for BSCI) and operation and maintenance (5–66%; 29–92% for BSCI), while architecture and external environment have the smallest spreads, as the sampled buildings are situated in a small geographical area.

6. Concluding remarks

This paper developed two simple and cost-effective assessment schemes to evaluate the health and safety performance of multi-storey residential buildings in Hong Kong. We found that there were considerable variations in health and safety conditions across buildings, even though they are located in the same district. Neglecting and tolerating poor building health and safety conditions could now make a high-density society pay a higher price in the future. We found that most of the variations in building health and safety conditions were attributed to differences in building management systems rather than building designs. Enhancing strategic management approaches (e.g. better delineation of owners’ rights and duties) appears to be the first step that underperformers should take in order to improve their buildings and living conditions.

To encourage more sustainable buildings at the community level, the assessment results can be summarized into two simple and user-friendly performance indicators for public consumption, namely the BHHI and the BSCI. By publicizing these performance indices, the public would be better informed of the health and safety risks of different buildings so that building owners, developers, and government bodies can make more informed and socially responsible decisions in the future. It is envisaged that further research can be conducted to investigate the relationship between building performance and extraneous factors, such as building age, management structure, and scale of development. Although the assessment scheme is currently designed for apartment buildings in Hong Kong, it can be easily modified and adapted to suit the technological, cultural, and social settings of other places.

\(^{10}\) Generally speaking, an older building is poorer in structural and other physical conditions due to the natural deterioration of the building’s fabrics and services, so a lower management score resulted. On the other hand, the design component also tends to be age-related because the regulatory requirements are upgrades over time and the awarding of a lower design score to these buildings.
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Appendix A. Sample questionnaire for the structured interview

| Items                                           | Description                  |
|------------------------------------------------|------------------------------|
| Management fee ($)                             | Per flat (per flat):         |
|                                                | or Per area (per m²):        |
| Frequency of cleaning                          | Entrance Lobby: ___________ per day |
|                                                | Upper Lobbies: ___________ per day |
|                                                | Lift (or Staircase): ______ per day |
| Frequency of refuse removal                    | Frequency: ______ per day    |
| Frequency of pest control                      | Frequency: ______ per month  |
|                                                | How: Remove Stagnant Water   |
|                                                | Apply Pesticide              |
|                                                | Engage Pest Control Contractor|
| Regular inspection on water and drainage systems| Water (Frequency __________) |
|                                                | Drainage (Frequency ______)  |
|                                                | Not at all                   |
|                                                | By whom?                     |
|                                                | Professional Staff           |
|                                                | Property Attendant            |
| Regular inspection on other building services  | Fire Services (Frequency ______) |
|                                                | Lifts & Escalators (Frequency ______) |
|                                                | Gas Supply (Frequency ______) |
|                                                | Electrical installation (Frequency ______) |
| Professional engaged to produce report on structural safety | Yes |
|                                                | No                           |
| Inspection on windows by professionals         | Yes (Frequency ______)       |
|                                                | No                           |
| Regular tenant survey                          | Hygiene (Frequency ______)   |
|                                                | Safety (Frequency ______)    |
|                                                | Not at all                   |
| Regular fire drills                            | Yes (Frequency ______)       |
|                                                | No                           |
| Keeping of incidence records                   | Falling objects, lift failure|
|                                                | Bursting of pipes, stoppage of water|
|                                                | No                           |
| Presence of as-built drawing records           | General Building Plans       |
|                                                | Building Services Plans      |
|                                                | No                           |
| Presence of planned maintenance programme      | Yes                          |
|                                                | No                           |
| Provision of evacuation plan or fire safety plan to occupants | Yes |
|                                                | No                           |
| Insurance policy taken                         | Third Party Liability        |
|                                                | Property-all-risk            |
|                                                | No                           |
| Presence of sinking fund for future renovation | Sinking Fund: $ __________ |
|                                                | Financial Reserve: $ ______   |
| Head Office Contact                            | Tel. No.: __________________ |
|                                                | Contact Person: ____________ |

End of Questionnaire
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