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Review of low-carbon refurbishment solutions for residential buildings with particular reference to multi-story buildings in Hong Kong

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ABSTRACT

As the second largest GHG emitter in the world, the building sector needs to play an active role in reducing GHG emissions. Particular attention should be directed to existing buildings, not only because of the amount of emissions caused by inefficient buildings but also due to the existence of a variety of sustainable refurbishment solutions for different levels and stages of building refurbishment. The emission reduction performance of different sustainable refurbishment options, however, varies enormously as a result of different building design conditions. Cooling, for example, is a much more important consideration than heating in warmer climates. For high-rise multi-story existing buildings, due to the complexity of the occupant mix and their emission reduction goals, more attention should be paid to reducing the energy consumption of common areas and increasing the energy performance of the building envelope. This paper provides a comprehensive literature review of the nature and assessment of existing sustainable refurbishment options for residential buildings in sub-tropical high-density cities such as Hong Kong. The paper will also help policy and decision-makers delineate a set of sustainable refurbishment solutions that are suitable for multi-story buildings to maximize the opportunity for reducing their emissions.

1. Introduction

The commonly known definition of *sustainable development* was made by the World Commission of Environment and Development in 1987, calling for development “that meets the needs of the present without compromising the ability of future generations to meet their own needs”. This statement brought about the need for integrated decision making that would be able to balance human economic and social demands with the regenerative capacity of the natural environment [1]. A broader terminology was put forward to encompass the economic, social and environmental principles of the “triple bottom line” [2].

Each of the three components is given equal attention in considering sustainable development. The *economic principle* is to increase people's income over time without threatening the regeneration of nature [3]. This approach calls for careful economic analysis of the costs and benefits of developmental and environmental policies that will strengthen environmental protection and improve the level of social welfare [4]. The *social principle* refers to the harmony of social and cultural systems. For instance, more benefits should be directed to the poor, including increases in the provision of food, real income, education, health care and water supply, none of which are entirely equivalent to economic growth [5]. In addition, it also requires businesses to contribute to economic development while enhancing the living standard of the workforce and the families involved, which is considered a corporate social responsibility [6]. The *environmental principle* aims at maintaining essential ecological processes and life support systems, preserving genetic diversity, and utilizing the species and ecosystems in a sustainable manner [7]. Examples of efforts to promote this principle include the Montreal Protocol, designed to enable a significant reduction in recognized ozone depletion substances [8], the Kyoto Protocol to mitigate carbon emissions [9], and the Harbor Effluent Export Scheme implemented by the Hong Kong government to control the impact of algal blooms. Sustainable development involves the mutual interaction of all three components.

The building sector is responsible for 40% of energy consumption and 30% of GHG emissions worldwide [10]. Taking into account the massive growth of new construction and the great number of inefficient existing buildings, carbon emissions from the building sector are expected to more than double in the next 15 years if the ‘business-as-usual’ scenario continues [10]. In developed countries and regions such as the UK and Hong Kong, the ratio of new buildings to old is

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lower than 4% each year [11,12]. The existence of a huge number of inefficient existing buildings compound the GHG emissions of a city, making efforts to mitigate the carbon intensity of existing buildings indispensable [13].

Considerable experience of sustainable refurbishment has been accumulated around the world as it is considered to be essential in reducing the amount of GHGs emitted by existing buildings [14–16], and a great number of sustainable refurbishment approaches have been developed for both residential buildings [17–19] and non-residential buildings [20–22]. The quantification of emission reductions resulting from these approaches remains an area of interest for research scientists [23–25] and provides support for studies of decision making for sustainable refurbishment (e.g. Jaggs and Palmer [26] and PRUPIM Developments [27]). However, as most research into sustainable refurbishment has been conducted in North American/European countries, the distinctive climatic features and building characteristics of those areas may render such approaches unsuitable or ineffective for application in such high-density subtropical cities as Hong Kong [28]. It is, therefore, important to understand the suitability and emission reduction performance of various sustainable refurbishment options in reference to the local situation.

Until now, many research projects in Hong Kong have been directed towards enhancing the energy efficiency of offices and commercial buildings. Examples of these include studies of the optimal control of building HVAC systems [29,30], fault detection and diagnosis strategy for HVAC systems [31,32], demand control ventilation strategies [33], summaries of energy saving measures [34,35] and the shading effects of buildings [36]. The better known explorations of suitable approaches to lower the energy consumption of residential building stocks remain relatively sparse, however, and mainly focus on the improvement of insulation [37], glazing systems [38,39] and air-conditioning [40,41].

In response, the objectives of this paper are (i) to provide a comprehensive review of the most suitable existing sustainable refurbishment options for residential buildings in subtropical regions; and (ii) to understand their suitability for high-rise multi-story buildings with multiple occupants such as occur in Hong Kong. A list of 88 sustainable refurbishment approaches is identified, of which 39 are considered relevant to Hong Kong's climate and building characteristics. The solutions are further classified according to three levels of scale of refurbishment together with the detailed practical implications for Hong Kong and other similar situated cities.

2. Building life cycle GHG emissions

The carbon footprint refers to the total GHG emission produced directly and indirectly by an individual, organization, event or product expressed in the form of carbon dioxide equivalent (CO_2e) [42]. CO_2e is calculated by multiplying the emissions of each of the six GHGs by their 100-year global warming potential, as defined by the IPCC [43]. According to Carbon Trust [42], the carbon footprint can be measured based on either organization or product. An organizational carbon footprint measures the GHG emissions caused by all the activities of an organization, including energy consumption in buildings, operational processes and transportation, while a product carbon footprint measures the GHG emissions across the life of a product, from raw material and manufacturing through consumption and demolition [42].

While numerous studies have explored the life cycle carbon emission and energy consumption of commercial buildings [44–47], few focus on the residential sector. Examples of such studies include the life cycle energy consumption of single dwellings in Sweden [48] and the embodied energy in building materials over the whole life of high-rise residential blocks in Hong Kong [45].

Despite the difference in building types, the life cycle carbon emissions of a building are commonly divided into four phases: initial emission, operational emission, renovation emission and demolition emission [44]. The sources of GHG emissions in each phase of a building's life cycle and their estimated proportion are shown in Table 1. As can be seen, the building's operational phase is the major source of life cycle GHG emissions (60–90%), followed by the initial phase (10–40%), which includes emissions from materials, transportation and the construction process itself. The GHGs emitted in the renovation and demolition stages are relatively minor.

Table 1
Source and estimated proportion of GHG emissions in different phases of buildings' life cycle [44,45,48,49].

Phase of building life cycle	Source of emission	Estimated proportion of total GHG emission
Initial	Manufacturing Transportation Construction process	10–40%
Operation	Daily operation	60–90%
Renovation	Materials Process of renovation	0–10%
Demolition	Demolition activities Landfill	0–10%

Thus, energy performance during the operational stage plays the essential role in the life cycle emissions of a building. As the amounts of GHG emissions vary significantly (from 60% to 90%) and the degradation of energy efficiency tends to be inevitable in the operational stage of buildings, there is great potential for emission reduction through refurbishing existing buildings in a sustainable manner. However, although renovation accounts for a minor proportion of GHG emissions (10%), little is known of the relationship between the emission level in the renovation stage and that in the operation stage.

3. Sustainable refurbishment

According to the Oxford Dictionary [107], to "refurbish" is defined as to "renovate and redecorate (something, especially a building)". Definitions that are more detailed have been given by professional groups for major and minor refurbishments. For instance, the Building Research Establishment [50] defines a major refurbishment project as an activity that results in the provision, extension or alteration of thermal components and/or building services and fittings, these components including: (1) thermal elements such as walls, roofs and floors; (2) fittings such as windows and entrance doors; and (3) building services like lighting [51], heating and cooling, and the operation of pumps. Similarly, the U.S. Green Building Council [108] defines major refurbishment as consisting of the significant modification and internal rehabilitation of HVAC.

These descriptions indicate that the scope of the involved elements plays an important role in defining different refurbishment projects, as this dictates the type of assessment methodology to be used [11]. Moran et al. [52] have developed a four-level classification of refurbishment comprising

(1) *Light touch:* repair and upgrade minor elements of the building;
(2) *Medium intervention:* replace building services in part of the building;
(3) *Extensive intervention:* replace building services and make some fabric changes; and
(4) *Comprehensive refurbishment:* which covers the scope of Levels 1–3 and includes development opportunities outside the building.

In assessing the building's condition and performance, Shah [11] has established four levels of refurbishment similar to those given above, adding demolition as a fifth level.

These studies reveal the scale of altered components to be a key concern in identifying different levels of refurbishment. However, other