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Green Retrofitting Aged Residential Buildings: An Empirical Study in Hong Kong

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Abstract

Given the urgent needs to reduce carbon emission and energy consumption, green retrofit provides a sustainable solution to improve existing buildings' performance and contributes to a low carbon urban development. Accordingly, studies on the promotion of green retrofit technologies (GRTs) and green retrofit policies (GRPs) have received great attention globally. However, few research efforts have been done to study the implementation of GRTs and GRPs for particular regions such as Hong Kong. This paper aims to perform an empirical investigation on the promotion of GRTs and GRPs adoption within the context of Hong Kong. The findings of the paper are very useful for various stakeholders to have a better understanding of the GRTs and GRPs, such as their applicability and importance in the local applications. The priority guide provides a valuable reference for the local government to review their current policies, develop the future GRPs, and nurture a healthy environment for green retrofit. This study is significant for providing a fundamental guide for future research and development of green retrofit in local and global contexts.

Keyword: Green retrofit; Aged residential building; Technology; Policy; Hong Kong

1. Introduction

With the negative impacts of buildings on environment, building sector has to face the challenges of sustainable development (Seneviratne et al., 2016). The negative impacts on environment include natural resources use, material use, energy consumption, greenhouse gas emission, and waste. Furthermore, due to growing world population and rapid economic growth, more buildings are needed(Ashuri and Durmus-Pedini, 2010). In order to reduce buildings' negative impacts on environment, green retrofitting existing buildings provides a sustainable solution instead of construction of new buildings (Onat et al., 2014).

Comparing with new buildings, green retrofitting existing buildings has many benefits (Langston et al., 2008). According to the U.S. Green Building Council (USGBC), "green retrofit is any kind of upgrade at an existing building that is wholly or partially occupied to improve energy and environmental performance, reduce water use, and improve the comfort and quality of the space in terms of natural light, air quality, and noise". Green retrofit can improve energy and environment performance, service level and indoor environmental quality of existing buildings (Ciulla et al., 2016, Ma et al., 2012). Moreover, retrofitted buildings are more livable and comfortable for dwellers (Sweatman and Managan, 2010). Green retrofit can also preserve cultural, aesthetic, and heritage value of aged buildings (Wilkinson et al., 2009).

With the increasing awareness of green retrofit, many research efforts have been done on green retrofit of existing buildings. Based on the review, green retrofit depends on many factors, including technologies, policies, client expectations, building features and other uncertain factors (Ma et al., 2012). Among these factors, green retrofit technologies (GRTs) and green retrofit policies (GRPs) are more important for the success of green retrofit (Jagarajan et al., 2017). Different GRTs have been applied in real cases, such as green roof (Castleton et al., 2010) and sensors (Nagy et al., 2014). GRPs are necessary for promoting green retrofit of existing buildings. Relevant research on policies have been done, such as building energy-efficiency retrofit policies (Kerr et al., 2017).

In Hong Kong, the energy consumption in residential buildings accounts for 22% of the total energy use (Langston et al., 2008). Moreover, over 89% of the residential buildings in Hong Kong were built before 1998, most buildings are not regularly maintained with safety and security problems, and poor indoor air quality (Tan et al., 2018). Many aged buildings have to be maintained or retrofitted due to poor performance. This paper aims to examine the applicable GRTs and GRPs and promote green retrofit of aged residential buildings in Hong Kong. The findings can help various stakeholders have a better understanding of the GRTs and GRPs and their priority level within the context of Hong Kong. The findings can also help the local government to develop future green retrofit policies.

2. Literature review

Retrofit is the "change" of elements or components of a building. Wherein, the "change" for green retrofit is limited to the "upgrade", which can improve a building performance (Liang et al., 2016). Therefore, retrofitting of existing buildings offers significant opportunities for reducing energy consumption and greenhouse gas emission. This has been considered as an effective solution for achieving sustainability in the built environment with relatively low cost and within short time (Ma et al., 2012). Various retrofit technologies and policies have been adopted in practice (Ebrahimi et al., 2017, Golubchikov and Deda, 2012). However, few research has been done on examining green retrofit technologies and policies for a particular region, such as Hong Kong. In order to identify the applicable GRTs and GRPs for Hong Kong, a comprehensive review of relevant literature has been done.

The availability of technology and its advancement are considered as key factors for the success of building green retrofit (GhaffarianHoseini et al., 2013). Building retrofit technologies are energy conservation measures to improve building energy efficiency and sustainability (Ma et al., 2012), which range from the changes in energy consumption patterns (e.g., the use of energy efficient equipment and renewable energy systems) to the application of advanced heating and cooling technologies. However, based on the research of Ebrahimi et al. (2017), suitability for specific use, characteristics of buildings and the local environment are important for identifying applicable refurbishment methods. Simultaneously, the applicability of retrofit measures should be examined by considering their economic payback, complexity and implementation difficulty (CIBSE, 2004). Tan et al. (2018) identified 28 GRTs which are suitable for aged residential buildings in Hong Kong, by considering the natural condition (e.g., subtropical climate, high-density city) and the characteristics of aged residential buildings (e.g., pattern of energy consumption, suitability for residential building, high-rise buildings), as shown in **Table 1**.

Table 1 *List of green retrofit technologies (GRTs)*

Categories		Code	Applicable GRTs in Hong Kong
Building service	Lighting (BS1)	BS1-1	Low energy lamps (T5 fluorescent)
		BS1-2	Light emitting diode (LED) lighting
		BS1-3	Daylight/Motion sensors
	Lift (BS2)	BS2-1	Lifts with power regeneration system
		BS2-2	Modernize lifts with a VVVF (Variable Voltage Variable Frequency) control system
		BS2-3	Lifts with permanent magnet motor
	Cooling (BS3)	BS3-1	Evaporative cooling
		BS3-2	Energy efficient room air conditioner
	Appliances and equipment (BS4)	BS4-1	Time switches
		BS4-2	Energy efficient appliances and equipment selection
		BS4-3	Installing meters for energy auditing
		BS4-4	Domestic water saving devices
		BS4-5	Grey water reuse and rainwater harvesting
Building envelope	Roof & wall (BE1)	BE1-1	Reflective surface (cool roof/wall) Green
		BE1-2	wall/roof
	Windows (BE2)	BE2-1	Window frames with thermal brake Reflective
		BE2-2	glazing
		BE2-3	Double/multiple glazing
	Shading (BE3)	BE3-1	Overhangs/Vertical fin Automatic
		BE3-2	blinds
	Insulation (BE4)	BE4-1	External wall insulation
		BE4-2	Internal wall insulation
		BE4-3	Roof insulation
	Air tightness (BE5)	BE5-1	Joint sealing
		BE5-2	Draught-proofing
Renewable energy (RE)		RE1	Solar water heating
		RE2	Building-integrated photovoltaics

RE3	Building-integrated wind turbine

Note: The GRTs was adapted from Ref. (Tan et al., 2018)

Besides technologies, polices play important role in promoting green retrofit of existing buildings. Golubchikov and Deda (2012) pointed out that progress towards energy saving requires a strong institutional milieu stimulating deployment of technological solutions. Based on the previous studies, building policies, codes and regulations are essential for promoting green retrofit (Shi et al., 2013), and conducive to increase green retrofit technologies adoption (Darko and Chan, 2018). Given the significance of GRPs, it is necessary to identify suitable green retrofit policies in Hong Kong. Shen et al. (2016) proposed that the different environments result in various policies, and effective policies should fit the local development. Thus, based on previous research, Tan et al. (2018) identified 18 suitable GRPs by considering the local context (e.g., political system, economic level and environmental condition) in Hong Kong, as shown in **Table 2**.

Table 2 *List of green retrofit policies (GRPs)*

Categories	Code	Recommended GRPs for Hong Kong
Direction-based policies (DP)	DP1	Formulate strategy for building green retrofit
	DP2	Develop a building green retrofit action plan
	DP3	Develop a guideline on building green retrofit
Regulation-based policies (RP)	RP1	Incorporate green retrofit element in existing mandatory schemes (e.g., MBIS, MWIS)
	RP2	Formulate codes, standards and regulations (CSR) for building green retrofit
	RP3	Promotion programs for green retrofit
Evaluation-based policies (EP)	EP1	Establish a new evaluation system for green retrofit or incorporate green retrofit element in existing evaluation systems (e.g., BEAM-Plus)
	EP2	Establish a labelling system for building green retrofit
Financial support policies (FP)	FP1	Research funds for building green retrofit
	FP2	Low interest loans for green retrofit projects
	FP3	Tax reduction for building green retrofit companies
	FP4	Initiate subsidy scheme for green retrofit projects
Organization & professional training (OP)	OP1	Establish an institution of green retrofit or create a green retrofit branch in existing institutions
	OP2	Provide relevant professional education and training
	OP3	Encourage specialist contractors in green retrofit
Knowledge & information (KI)	KI1	Promotion programs for public awareness of green retrofit
	KI2	Provide a platform for knowledge & experience sharing (e.g., APP, website, seminar, conference)
	KI3	Encourage innovation in building green retrofit

Note: The GRPs was adapted from Ref. (Tan et al., 2018)

Many research efforts have been done on different green retrofit technologies and policies, and their applications in real cases. However, few studies have been done to identify the relative importance and priority of GRTs and GRPs for a specific region. Therefore, this paper aims to provide an empirical investigation on the promotion of GRTs and GRPs adoption within the context of Hong Kong.

3. Research methodology

3.1. Data collection

In this study, a questionnaire survey was conducted to gather the professional views on the applicability of GRTs and the importance of GRPs. The questionnaires were distributed to 500 professionals in Hong Kong by mail to collect their opinions about selected green retrofit technologies and policies. The respondents include the consultants, contractors and research institutes. Questionnaire was designed based on the pre-identified 28 GRTs and 18 GRPs. Respondents' background information and opinions on the GRTs and GRPs were collected. Respondents were requested to indicate their opinions by using a five-point Likert scale (1 = not important, 2 = less important, 3 = neutral, 4 = important, and 5 = very important) (Ekanayake and Ofori, 2004). The research team finally received 61 responses through online, email, mail or fax. After filtering, 59 responses were valid. The collected data were reliable with Cronbach's alpha coefficient value 0.932, which is higher than 0.70 (Darko and Chan, 2018).

The details of the respondents' profiles are shown in **Table 3**.

Table 3 *Demographic Information of respondents（N=59）*

Item	Personal particulars	Percentage	Item	Personal particulars	Percentage
Age	20-29	16.90	Working life	<5 years	18.60
	30-39	25.40		5-10 years	18.60
	40-49	27.10		11-15 years	11.90
	50-59	11.90		16-20 years	3.40
	60+	18.60		>20 years	47.50
Educational background	High school or below	5.10	Professionals	Consultant	27.10
	Undergraduate	13.60		Contractor	32.20
	Postgraduate	81.40		Research institute	40.70

3.2. Statistical data analysis

With the aid of the SPSS 21.0 statistical package, the data collected from the survey were analyzed by using various statistical analysis methods (Nie et al., 1975). First, ranking analysis was conducted. The rankings of GRTs and GRPs were determined based on the mean score ratings (Ann et al., 2007). Moreover, to analyze the agreement amongst the respondents regarding the rankings of the GRTs and GRPs, Kendall's coefficient of concordance (Kendall's W) test and Kruskal–Wallis test were conducted (Darko and Chan, 2018; Ann et al., 2007). Besides, the Pearson Correlation analysis was conducted to analyze the correlations between the GRTs and GRPs. Based on above analysis, the priority levels of GRTs and GRPs can be identified, and a priority guide can be developed to promote green retrofit of aged residential buildings in Hong Kong.

4. Results

4.1. Results of GRTs Analysis

Respondents were invited to rate the applicability of the pre-identified green retrofit technologies in Hong Kong, and add new GRTs if necessary. The survey results are shown in **Table 4**. For all respondents, all the mean scores are greater than 3.00, which indicates that all the GRTs are considered applicable in Hong Kong. It also indicates that the importance of green retrofit has been recognized by the local professionals. The top three GRTs (mean ≥4.00) are “energy efficient appliances and equipment selection” (BS4-2), “energy efficient room air conditioner” (BS3-2) and “low energy lamps (T5 fluorescent)” (BS1-1). The results indicate that these three GRTs have high application priorities for green retrofit of aged residential buildings in Hong Kong. By contrast, “building-integrated wind turbine” (RE3), “automatic blinds” (BE3-2) and “internal wall insulation” (BE4-2) are bottom three GRTs, indicating there are limitations or difficulties when applying these technologies in Hong Kong.

Table 4 *Survey results on the 28 GRTs*

GRTs	All respondents (N=59)		(1) Consultant (N=16)		(2) Contractor (N= 19)		(3) Research institute (N=24)	
	M	Rank	Mean	Rank	Mean	Rank	Mean	Rank
BS4-2	4.15	1	4.00	1	4.05	2	4.33	1
BS3-2	4.03	2	3.88	3	3.84	6	4.29	2
BS1-1	4.02	3	4.00	1	4.16	1	3.92	6
BS4-1	3.98	4	3.75	8	3.89	5	4.21	3
BS1-2	3.97	5	3.75	8	4.05	2	4.04	5
BS4-4	3.88	6	3.81	6	3.68	9	4.08	4
GRTs	All respondents (N=59)		(1) Consultant (N=16)		(2) Contractor (N= 19)		(3) Research institute (N=24)	
	M	Rank	Mean	Rank	Mean	Rank	Mean	Rank
BE4-3	3.81	7	3.86	5	3.74	7	3.71	10
BS1-3	3.78	8	3.43	16	4.05	2	3.79	9
BE2-3	3.64	9	3.69	10	3.53	10	3.71	10
RE1	3.64	9	3.81	6	3.42	12	3.71	10
BE1-1	3.59	11	3.88	3	3.21	21	3.71	10
BE2-1	3.58	12	3.38	17	3.32	15	3.92	6
BE2-2	3.56	13	3.50	13	3.16	23	3.92	6
BE5-1	3.54	14	3.25	20	3.74	7	3.58	21
BS2-1	3.54	14	3.63	11	3.26	18	3.71	10
BE1-2	3.53	16	3.63	11	3.32	15	3.63	18
BE3-1	3.47	17	3.50	13	3.26	18	3.63	18
BE4-1	3.47	17	3.38	17	3.32	15	3.67	17
BE5-2	3.46	19	3.00	27	3.11	24	3.71	10
BS2-3	3.44	20	3.25	20	3.42	12	3.58	21
BS2-2	3.42	21	3.44	15	3.37	14	3.46	25
BS4-3	3.41	22	3.25	20	3.26	18	3.63	18
RE2	3.39	23	3.06	26	3.47	11	3.54	23
BS3-1	3.32	24	3.19	24	3.21	21	3.50	24
BS4-5	3.29	25	3.13	25	2.89	27	3.71	10
BE4-2	3.25	26	3.25	20	3.11	24	3.38	26
BE3-2	3.17	27	3.31	19	3.00	26	3.21	28
RE3	3.05	28	2.94	28	2.79	28	3.33	27

Note: The Kendall's W for ranking the 28 GRTs is 0.106 with a significance level of 0.000.
*The Kruskal-Wallis H test result is significant at the significance level of 0.05 (p-value < .05).

4.2. Results of GRPs Analysis

The survey results of GRPs are shown in **Table 5**. There are also no additional policies suggested by the respondents. All the mean scores of the GRPs are greater than 3.50. It indicates that all the identified GRPs are important for promoting green retrofit of aged residential buildings in Hong Kong. Based on the ranking, there are eight GRPs with the mean scores above 4.00, including “tax reduction for building green retrofit companies” (FP3), “research funds for building green retrofit” (FP1), “formulate codes, standards and regulations (CSR) for building green retrofit” (RP2), “promotion programs for public awareness of green retrofit” (KI1), “develop a guideline on building green retrofit” (DP3), “initiate subsidy scheme for green retrofit projects” (FP4), “formulate strategy for building green retrofit” (DP1) and “encourage innovation in building green retrofit”(EP2). The results indicate that these GRPs were considered the most important policies to promote GRTs and practices adoption, and local government should pay more attention on these policies. Moreover, three policies are considered less important, including “establish a labelling system for building green retrofit” (EP2), “establish an institution of green retrofit or create a green retrofit branch in existing institutions” (OP1) and “incorporate green retrofit element in existing mandatory schemes (e.g., MBIS, MWIS)” (RP1).

Table 5 *Survey results on the 18 GRPs*

GRPs	All respondents (N=59)		(1) Consultant (N=16)		(2) Contractor (N= 19)		（3）Research institute (N=24)	
	Mean	Rank	Mean	Rank	Mean	Rank	Mean	Rank
FP3	4.19	1	4.00	3	4.11	2	4.38	2
FP1	4.15	2	4.00	3	4.21	1	4.21	6
RP2	4.12	3	4.06	2	3.89	5	4.33	3
KI1	4.12	3	4.19	1	4.00	4	4.17	7
DP3	4.10	5	3.94	5	3.84	7	4.42	1
FP4	4.07	6	3.88	9	3.89	5	4.33	4
DP1	4.03	7	3.81	11	4.05	3	4.17	7
KI3	4.02	8	3.88	9	3.79	10	4.29	5
KI2	3.93	9	3.94	5	3.74	11	4.08	12
DP2	3.90	10	3.88	8	3.84	7	3.96	17
OP2	3.90	10	3.94	5	3.74	11	4.00	15
RP3	3.88	12	3.75	13	3.79	9	4.04	13
FP2	3.86	13	3.75	13	3.63	14	4.13	9
EP1	3.83	14	3.63	17	3.74	11	4.04	13
OP3	3.83	14	3.69	16	3.58	15	4.13	9
RP1	3.75	16	3.56	18	3.42	17	4.13	9
OP1	3.75	16	3.81	11	3.37	18	4.00	15
EP2	3.69	18	3.75	13	3.47	16	3.83	18

Note: The Kendall's W for ranking the 18 GRPs was 0.064 with a significance level of 0.05.
*The Kruskal-Wallis H test result is significant at the significance level of 0.05 (p-value < .05).

5. Discussion

Based on the above discussions, a priority guide for promoting green retrofit of aged residential buildings implementation in Hong Kong was developed, as shown in **Fig.1**. According to the arguments proposed by Tam et al. (2016) and Peri et al. (2017), retrofitting budgets do not always meet the ever-increasing needs. There is a need to set the priorities of different GRTs and GRPs. Priority setting is normally based on the professional knowledge and experience of building professions, and GRTs and GRPs with high rankings normally have high priorities. In this study, the priority setting is category based. After in-depth analysis of the rakings, correlations, and each category, three priority levels of GRTs and GRPs were identified, namely Tier 1 (high priority), Tier 2 (medium priority) and Tier 3 (low priority), as shown in **Fig. 1**.

As mentioned above, retrofit measures should be considered according to their economic payback, complexity and ease of implementation (CIBSE, 2004). Giving the discussion above, the GRTs with the high priority included BS1 (lighting), BS3 (cooling) and BS4 (appliances and equipment) (see **Fig.1**). These technologies are cost effective, easy to implement and have the prominent performance of energy saving, and also have high rankings according to the survey. Moreover, the technologies, including BE1 (roof & wall), BE2 (windows) and BE5 (air tightness), were identified as Tier 2 GRTs with medium priority. According to the survey result, these technologies have lower rankings comparing with Tier 1. For example, “reflective glazing” (BE2-2) is a kind of technology for minor retrofit with relatively low cost and easy application (Ebrahimi et al., 2017). However, reflective glazing has less visible light transmission, and the sunlight can be easily blocked by neighboring buildings in high-density cities, such as Hong Kong (Lee et al., 2014). Furthermore, BS2(lift), BE3(shading), BE4 (insulation) and RE (renewable energy) were grouped into the third priority level, Tier 3 because there are limitations or difficulties when applying these technologies on aged residential buildings in Hong Kong. For example, technologies in BS2 and BE4, involve high retrofit cost, long time and high disturbance to the occupants. The application of technologies in BS2 and BE4 is on a case-by-case base, not suitable for large-scale implementation. Technologies in BE3 also involve high cost, disturbance to occupants (BE3-2 Automatic blinds) and technical problems for installation (BE3-1 Overhangs/Vertical fin).

Furthermore, the application of GRTs in local aged residential buildings requires the support of relevant GRPs. The identified 18 GRPs were further analyzed by considering the function of each retrofit policy and the characteristics of the retrofit gradation (Tan et al., 2018), and grouped into three priority levels, as shown in **Fig. 1.** DP (direction-based policies), FP (financial support policies) and KI (knowledge & information) are in Tier 1 with high priority.

Due to the lack of the experience and knowledge of building green retrofit, direction-based policies, including green retrofit strategy, action plan and guideline, should be developed with high priority level at the early stage of green retrofit implementation. RP (regulation-based policies) and OP (organization & professional training) are in Tier 2 with medium priority. The policies in Tier 1 will create a green retrofit market. There is a need to regulate the market and provide relevant professional trainings to ensure the healthy development of green retrofit. Regulations set the standards and requirements for retrofitting existing buildings (Ma et al., 2012). However, standardization is a complex process and needs time and relevant experience (Pawson et al., 2005). Therefore, RP and OP should be carried out when the market will go up, with relevant experiences and lessons. EP (Evaluation-based policies) is in Tier 3 with low priority. After the mature of the market, the EP should be considered to evaluate and improve the efficiency of green retrofit. There are difficulties when developing evaluation-based policies, such as complex data collection, evaluation software development and lack of professional assessors etc. (Song et al., 2012), which is echoed by the professionals from the survey (see **Table 6**). Therefore, evaluation-based policies can be developed at a later stage to ensure the green retrofit efficiency.

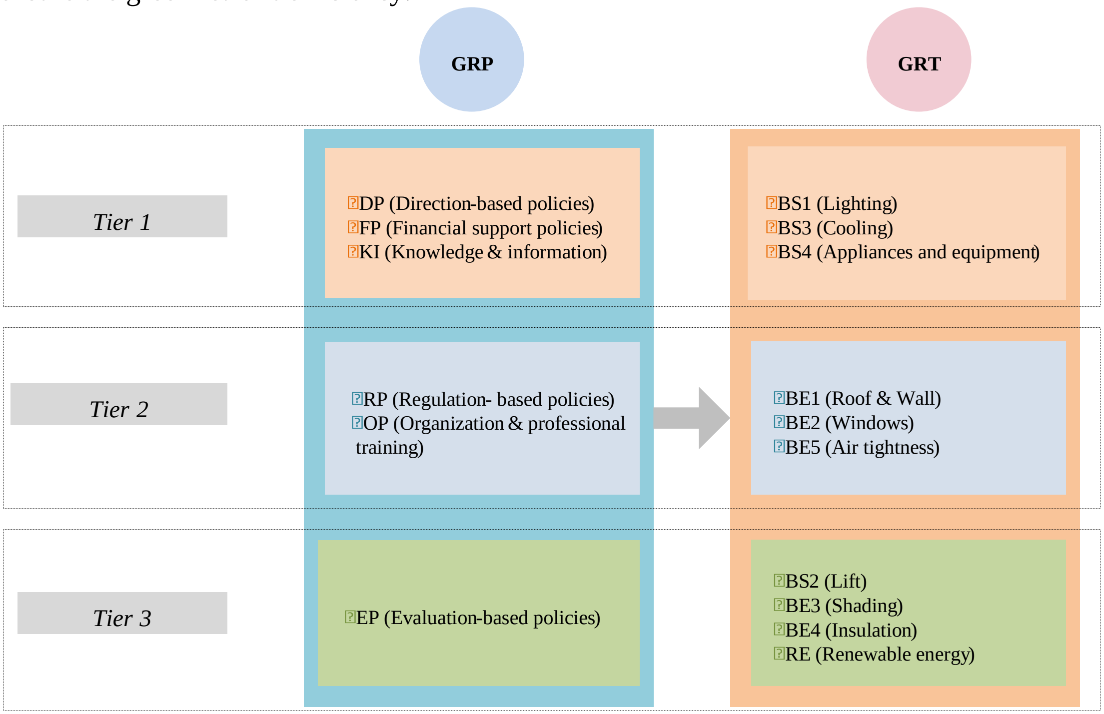

Fig. 1 *Priority guide for green retrofit of aged residential buildings in Hong Kong*

6. Conclusion

With the increasing number of aged buildings in Hong Kong, green retrofit has been considered a good solution to address multiple sustainability issues. Green retrofit techniques and policies are important for promoting green retrofit, because they provide knowledge, regulation and guideline for the industry to follow. However, few relevant studies have been done and there are still many problems in current green retrofit practice. Inadequate green retrofit knowledge and relevant policies have limited the promotion of green retrofit in Hong Kong. Therefore, this study aims to examine the applicability of GRTs and the importance of the GRPs for green retrofit of aged residential buildings in Hong Kong. Based on the in-depth analysis of the findings from the survey and the features of the GRTs and GRPs, a priority guide for green retrofit of aged residential buildings in Hong Kong was developed, which grouped the GRTs and GRPs into three priority levels, namely Tier 1 (high priority), Tier 2 (medium priority) and Tier 3 (low priority). The findings also provide guidance for the local Government to develop future green retrofit polices, and ensure a healthy development of green retrofit in the city.

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