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Green Building Rating Systems and Construction Waste in High Density Urban Environment: The Case Study of Hong Kong

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Abstract: Hong Kong, as many other countries, is currently facing a waste management crisis with the shortage of reclamation sites and landfill space. Examination of construction waste management (CWM) criteria within Hong Kong's BEAM Plus is limited and lacking. In this paper, CWM criteria were assessed and a case study was conducted on a recent project, pursuing BEAM Plus, to assess the effectiveness of CWM criteria to facilitate waste reduction. The findings revealed that the overall impact of BEAM Plus on construction waste reduction is negligible. The case study showed that the reasons material/waste-related credits are not commonly attempted is due to the lack of minimum thresholds and a low weighting relative to credits in other categories. In the case study, waste generated per constructed floor area was 0.21 tons/m2. This paper also makes recommendations to improve CWM criteria in BEAM Plus in order to promote a more sustainable building industry.

Keywords: Construction waste management, green building rating systems, materials, BEAM Plus

1. Introduction

1.1 Construction Waste Definitions and Management

Construction waste management has become a major environmental burden in many cities (Faniran and Caban, 1988; Kibert, 1994; Ferguson et al., 1995; Graham and Smithers, 1996; Gutherie et al., 1999; Symonds, 1999; Lawson and Douglas, 2001; Poon et al., 2004; Galvez-Martos et al., 2018; Huang et al., 2018; Lu et al., 2019). Worldwide, the definition of construction waste, aslo called construction and demolition debris varies according to countries or states. In Hong Kong construction waste is generally defined as a mixture of inert and non-inert materials arising from construction, excavation, renovation, demolition and roadwork (Legislative Council, 2006). The composition of construction waste varies and is highly dependent on the type and scale of construction activities generating waste. The composition of construction waste is subdivided in two major categories: the inert and the non-inert materials. The inert materials comprise soft inert materials such as soil, earth and slurry, and hard inert materials such as rocks and broken concrete. Recent statistics indicate that in Hong Kong the soft inert materials have accounted for about 70% of all construction waste and are only suitable for reuse as fill materials in reclamation and earth filling works (Legislative Council, 2006). However, the hard inert materials which account for about 12-15% of all construction waste can be either reused in

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reclamation works or recycled for construction works as granular materials, drainage bedding layers and concrete applications (Legislative Council, 2006). The non-inert waste, such as timber, plastics and packaging waste, account for about 15-18% of all construction waste and is recycled or disposed of in landfills. A recent study (Poon et al., 2004) revealed that timber formwork, wet trades of finishing work and concrete and masonry works were the major contributors to construction waste in building sites.

According to Skoyles and Skyoles (1987) there are two major types of construction waste such as structure waste and finishing waste. Structure waste includes concrete fragment, reinforcement bars, abandoned timber plates and pieces generated during the construction phase. Finishing waste includes a wide range of waste materials (surplus cement mortar, mosaic, tiles, paints, plastering materials, packaging materials) generated during the finishing phase of a building. Bossink and Brouwers (1996) estimated that about 1–10% by weight of the purchased construction materials ends up as waste on-site. In the UK, a research showed that at least 10% of all raw materials delivered to sites are wasted through damage, loss and over-ordering (Guthrie et al., 1998).

The European Commission (2015) has suggested that, by 2020, "the preparing for re-use, recycling and backfilling of non-hazardous construction and demolition waste excluding naturally occurring material defined in category 17 05 04" – i.e. soil and stones not containing dangerous substances – "in the list of waste shall be increased to a minimum of 70% by weight". Previous studies demonstrated that the recycling and reuse of construction waste could be used as concrete and masonry (Lim and Zollinger, 2003), road based material (Poon and Chan, 2006). Hendriks and Janssen (2001), demonstrated that about 90% of the recycled construction waste is generally composed of masonry and concrete.

1.2 Structure Construction Waste Management in Hong Kong

Hong Kong is an extremely dense city with a population of about 7.5 million (CSD, 2019). Limited available land and a dense urban environment has always been a challenge for Hong Kong. The total area of Hong Kong is 1106.7 km2, however, the developed area accounts for only 25%, and currently, Hong Kong is facing a shortage of reclamation sites and landfill spaces. The construction industry, which represented 5.2% of the Gross Domestic Productivity (GDP) in 2016, has a major impact on economic and environmental issues, consuming large amounts of energy and resources, and generates a significant amount of construction waste. According to the Hong Kong Environmental Protection Department (EPD), in 2016 about 24 million tonnes of construction waste was generated (representing about 66,796 tonnes per day), of which 6% was disposed of in landfills, and the remaining 94% in public filling areas (reclamation projects that take public fill). Construction waste accounted for 29% of the 15,332 tonnes per day disposal of solid waste at landfills. The statistics from the EPD showed that the existing three landfills will be full by 2019 (EPD, 2016).

To address the critical issue of construction waste, the Hong Kong Government has launched various regulations, codes, and initiatives to reduce the generation and disposal of construction waste to public filling areas, and landfills. Among these measures, the construction Waste Disposal Charging Scheme is recognized and proven to be effective at reducing waste going to the landfill (Hao et al., 2008; Lu and Tam, 2013; Yu et al., 2013), as well as implementing the 3R principles (Reduce, Reuse and Recycle) and the 'polluter pays' principle. The waste management philosophies of the 3R principles are part of the waste hierarchy from the EPD strategies for sustainable construction waste management (CWM). The 3R principles have become a common practice for policy makers and practitioners of sustainable solid waste management (Memon, 2010; Napier, 2012).

According to the waste hierarchy from the Construction Industry Research and Information Association (CIRIA), the different waste management options are ranked in the following hierarchy (Coventry and Guthrie, 1998):

(1) Reduction: (a) reducing the amount of waste produced, and (b) reducing the hazard of the waste produced.
(2) Reuse: putting materials back into use to avoid entering the waste stream.
(3) Recovery: (a) Recycling – collecting, and separating materials from waste and processing them to produce marketable products, (b) Composting – processing biologically degradable organic wastes aerobically to produce a reasonably stable, granular material, and (c) Energy – incinerating waste to generate energy.
(4) Disposal: disposal of waste to landfill site or land raised site.

However, effective CWM cannot solely depend on government effort but also requires collaboration from the industry. Poon et al. (2004) reported that on-site waste sorting and recycling is regarded as low priority for contractors, mainly due to low environmental awareness within the industry and the constraint of limited site areas. In the investigation of stakeholders' willingness to apply waste minimization strategies, only the Government showed a positive attitude while clients, contractors and designers remained neutral (Tam, 2008). In recent years, contractors' attitude and behavior towards on-site sorting and recycling have improved, leading to more effective resource reuse and recycling due to separating construction waste at the source (Yuan et al., 2013). Interestingly, on-site sorting performance is better in public projects than in private projects (Lu et al., 2016). Nevertheless, Yuan et al. (2013) pointed out that stakeholders' attitudes toward implementing on-site construction waste sorting are still regarded as the most critical factors in Hong Kong.

1.3 Description of Existing Methods and Tools

1.3.1. Building Assessment Methods – Definition and Role

Environmental building assessment methods are defined as "a way to evaluate the environmental performance of a building against an explicit set of criteria and typically consists of three major components (Cole, 2003):

- "A declared set of environmental performance criteria organized in a logical fashion – the structure.
- The assignment of a number of possible points or credits for each performance issue that can be earned by meeting a given level of performance – the scoring.
- A means of showing the overall score of the environmental performance of a building or facility – the output".

Over the years, assessment methods have evolved from 'environmental' to 'sustainable', embracing wider issues (economic, environmental, and social) with a long-term vision and responsibilities for the future. Assessment methods are used at various stages of a building's life to assess building performance (e.g. design, construction, operation). Voluntary assessment can supplement regulatory control leading to better environmental performance in the industry. Building owners can also gain a better public image from voluntary assessment (Lee and Yik, 2002).

CWM is addressed in the material use performance category of most rating tools. However, published research investigating how it is addressed in existing green building rating tools is limited (Ding et al., 2018; Doan et al., 2017; Wu et al., 2016). Lau (2013) compared the strengths and weaknesses of Hong Kong's BEAM Plus to ESGB and suggested improvements for the future revision of BEAM Plus in all assessment scopes. While there is interest in assessing CWM requirements among current green building certification systems, insight relevant to Hong Kong's construction industry remains limited.

1.3.2. BEAM Plus

Hong Kong Building Environmental Assessment Method (BEAM Plus) is a voluntary scheme developed in 1995 (as HK-BEAM), on behalf of the Real Estate Developers Association of Hong Kong. It is managed by the Hong Kong BEAM Society, an independent nonprofit organization. Since April 2011, BEAM Plus certification has become one of the prerequisites under the Building Ordinance for granting gross floor area (GFA) concessions for implementing certain green and amenity features. As of November 2015, 711 projects have registered for BEAM Plus version 1.1 and version 1.2 of 2010. Of these projects, 43.7% have been assessed. In this report, "BEAM Plus Version 1.2" (HKGBC, 2012) was used as reference. The main objectives of BEAM Plus are:

- Enhance the quality of buildings in Hong Kong
- Stimulate demand for buildings that are more sustainable, giving recognition for improved performance and minimizing false claims
- Provide a comprehensive set of performance standards that can be pursued by developers and owners
- Reduce the adverse environmental impact of buildings throughout their life cycle
- Ensure that environmental considerations are integrated right at the design and planning stages

Assessment methods have been developed for both existing buildings and new buildings. BEAM Plus defines good practice criteria for a range of environmental issues relating to planning, design, construction, and commissioning of buildings. The environmental categories in BEAM Plus include: Site Aspects, Material Aspects, Energy Use, Water Use, Indoor Environmental Quality, and Innovations and Additions. Registered projects undergo a two-step process to attain provisional and final ratings in Platinum, Gold, Silver, Bronze and unclassified (lowest rating). Three types of certificates are issued to projects depending on stages reached:

(1) Projects that have completed registration and are pending assessment
(2) Projects that have completed Provisional Assessment with a rating granted by the HKGBC (for design performance)
(3) Projects that have completed the Final Assessment with a rating granted by the HKGBC (for operational performance)

1.4 Objectives

The objectives of this paper were to conduct a comprehensive assessment of the construction waste management (CWM) criteria BEAM Plus in order to gain insight into improving the effectiveness of CWM criteria in Hong Kong BEAM Plus.

Objectives of this paper included:

(1) Assess Hong Kong's BEAM Plus green building rating tool
(2) Identify and analyze strategies within this tool for managing and minimizing construction waste
(3) Evaluate the importance assigned to waste-related issues in this green building rating tool
(4) Assess the use and achievability of waste-related Material Aspects (MA) credits in a case study of a typical high-rise residential project in Hong Kong
(5) Assess the effectiveness of MA credits in reducing waste in the selected case study

Some examples of how your references should be listed are given at the end of this template in the 'References' section, which will allow you to assemble your reference list according to the correct format and font size.

2. Methodology

2.1 Review of BEAM Plus Green Building Rating Tool

The CWM related criteria was identified. Once identified, the criteria were analyzed by categorization under a waste hierarchy (Reduce, Reuse, Recycle, Dispose), which included both prerequisite items and scoring items. This method is based on a content analysis method that has increasingly been adopted in the CWM field (Wu et al., 2016; Lu and Yuan, 2011; Zhang et al., 2012); it is a qualitative method to analyze text with existing theory or research (Hsieh and Shannon, 2005), allowing different focuses of the rating tools to be identified. In a previous study, Wu et al. (2016) analyzed and compared the relative importance of waste criteria in different rating tools with a relative significance index (RSI). An RSI enables comparison among different tools using a score scale.

The RSI equation was adopted in this review:

i. The rating tools BEAM Plus, were calculated using Eq.1.

$$\text{Eq. 1 RSI} = \Sigma\left(\frac{\text{CWMCi}}{\text{Sc}}\right) \times \frac{Sw}{Tw} \qquad (1)$$

- CWMCi refers to the maximum credits attainable of the construction waste management related item i;
- Sc and Sw refer to the credits and weighting of the corresponding assessment scope respectively,
- Tw represents the sum of all weighting from the assessment scopes.

The points (credits) are allocated based on requirements that follow the waste hierarchy of Reduce, Reuse, Recycle and Dispose. Different points are awarded to different strategy options for addressing the same issue.

2.2 Analysis of Hong Kong BEAM Plus Case Study

The detailed collection of case study data consisted of: (1) a project-oriented survey and (2) a face-to-face interview. The project-oriented survey included questions regarding attempted criteria within BEAM PLUS, and detailed information relating to perceived relevance and achievability of criteria within the Materials Aspects (MA) category. Other questions covered included: (1) general project information, (2) BEAM PLUS version, assessment stage and rating, (3) attempted credits in the MA category, (4) percentage of precast concrete per floor (by volume), (5) percentage of recycling waste and (6) waste management plan. The selection criteria for the case study included: the building type and height, year of completion (i.e. a recently completed project), project size, construction typology, and BEAM Plus rating level. The selected project was completed in 2015 and is presented in Table 1. The survey data was collected from a major contractor firm, from the Hong Kong building industry, involved in the project; while other data was collected from a face-to-face interview conducted with the contractor to substantiate the data collected in the survey. In this case study project, the total amount of construction waste generated and construction waste recycled was recorded by the contractor, in tons per month, according to the record of document to landfill (by truck) and receipt from the recycle company. The waste quantity was calculated with the same method from the Jaillon et al. study (2009) shown in Eq.2. The collected data was then compared with the projects constructed under JPNs (Hong Kong's Joint Practice Notes policies) 2001 & 2002 from Jaillon et al. study (2009), in which the average waste quantity of private sector residential building projects was 0.23 (tonnes/m2). The calculation method for comparing the case study with previous projects is shown in Eq.3. The calculation method for comparing recycled construction waste is shown in Eq.4.

$$\text{Eq.2 Waste quantity} = \frac{\text{Construction waste generated (ton)}}{\text{Construction Floor area (CFA) (m}^2\text{)}}$$

$$\text{Eq.3 Level of reduction} = \frac{\text{Pn}-\text{Po}}{\text{Po}} \times 100\%$$

Po: Waste quantity from the average of Projects using prefabricated technology from private sector in Jaillon et al. study (2009)

Pn: Waste quantity from the project in this research

Eq.4 Recycled construction waste

$$\frac{\text{Recycled Construction Waste}}{\text{Total Construction Waste}}$$

BEAM Plus includes 5 performance categories: Site Aspects (SA), Materials Aspects (MA), Energy Use (EU), Water Use (WU), and Indoor Environmental Quality (IEQ). In each performance category, there are numerous criteria with one or more credits per criteria. In this case study, the quantity of criteria and credits attempted in each performance category were considered. The percentage of criteria attempted in each performance category was calculated using Eq.5.

$$\text{Eq.5 \% of criteria attempted} = \frac{\text{Number of criteria attempted (Proj.)}}{\text{Number of criteria provided from BEAM Plus (Max.)}} \times 100\%$$

The percentage of credits attempted in each performance category was calculated using Eq.6.

$$\text{Eq.6 \quad \% of credits attempted} = \frac{\text{Number of credits attempted (Proj.)}}{\text{Number of credits provided from BEAM Plus (Max.)}} \times 100\%$$

According to BEAM Plus, “The Overall Assessment Grade is determined by the percentage of the applicable credits gained under each performance category and its weighting factor.” The calculating method of each performance category with weighting factor is shown in Eq 7.

$$\text{Eq.7 Credits attempted by weighting} = \frac{\text{Number of credits attempted (Proj.)}}{\text{Number of credits provided from BEAM Plus (Max.)}} \times \text{weighting factor}$$

Whereby the weighting factors of SA, MA, EU, WU, and IEQ are 25%, 8%, 35%, 12%, and 20% respectively – with a sum of all performance categories equaling 100%. The calculation method of the final score was the sum of all credits attempted taking into account the weighting of the performance category of each credit. The calculation method of each credit within a different category is shown in Eq.8. Since the case study was pursuing a gold rating, the minimum required percentage of credits attempted from the SA, EU, and IEQ categories was 60%; the minimum required percentage for the overall assessment grade was 65% (Table 2).

$$\text{Eq.8 1 credit in final score} = \frac{\text{Cc}}{\text{Tc}} \times \frac{\text{Cw}}{\text{Tw}}$$

Cc refers to the 1 credit of the related category c and Tc refers to the total credit of the related category c;

Cw and Tw represent the weighting of the related category and total weighting of the BEAM Plus rating system.

Table 1 - Hong Kong BEAM Plus case study details

Project description	3 towers with around 27 floors
	2-level podium
Construction year	2013-2015
Site area (m2)	8,250
CFA (m2)	66,000
BEAM Plus version	BEAM Plus New Buildings version 1.1
BEAM Plus rating	Provisional Gold
Podium construction	Cast-in-situ (Timber formwork)
Tower construction	Prefabricated non-structural elements and cast-in-situ
	(95%Steel formwork and 5% Timber formwork)
Precast % (by volume per typical floor)	15%
Prefabricated element types	Precast external facade walls and curtain wall
Design characteristics	Repetition on every typical floor
	Variations of layout on each towers

Table 2 - BEAM Plus Gold rating minimum requirement % of available credits achieved in each performance category and weighting factor of each performance category

Category	SA	MA	EU	WU	IEQ	Overall
Gold rating by % of available credits per category achieved	60%	-	60%	-	60%	65% #
Weighting factor (Sw)	25%	8%	35%	12%	20%	100%
Credit value in final score (Eq.9)*	1.14	0.36	0.83	1.33	0.63	-

*calculation without bonus credits
after weighting

3. Results and Discussion

3.1 Review of BEAM Plus Green Building Rating Tool

BEAM Plus recognizes waste as a sub-topic. BEAM Plus has five performance categories (Table 3), the fewest categories of all the tools, but consistent with those commonly found among other rating tools (e.g. Water use, Materials Use, Energy Use, Indoor Environmental Quality, and Innovation). Unlike the other systems, BEAM Plus does not address the Integrative Development process. Other categories, varyingly among the assessed rating tools, include: Transportation, Pollution, and Sustainable Site.

Table 3 - Weighting and scoring of the assessment scope, and ranking of waste criteria (relative significance)

Categories	Credits	Weight	CWM
Energy	44	35%	
Site Aspects	25	25%	
IEQ	35	20%	
Water Use	10	12%	
Materials Aspects	23	8%	{Materials 2.18% + CWM 5.82%
Innovation	6		
Total	137	100%	

*BEAM Plus – innovation: not included in the weight, hence the credits are excluded in total credits.

3.1.1 Assessment of Construction Waste Relevant Criteria

The RSI of each waste-related criterion, among the rating systems above, is shown in Table 3. BEAM Plus scores 5.82%, indicating that waste issues, within BEAM Plus, are considered relatively less important within the scope of green building design and construction. The CWM related criteria of BEAM Plus was further explored using the principles of Reduce, Reuse, Recycle, and Dispose.

Table 4 - Construction waste management related criteria

Waste- related criteria		Credits	Reduce	Reuse	Recycle	Disposal
MA P1	**Timber used for temporary work**	Required	Yes			
MA P3	**Construction/Demolition Waste Management Plan**	Required		Yes	Yes	Yes
MA 1	**Building Reuse**	2		2		
MA 2	**Modular And Standardized Design**	1	1			
MA 3	**Prefabrication**	2	2			
MA 4	**Adaptability and Deconstruction**	3	3			
MA6	**Sustainable forest product**	1			1	
MA 7	**Recycled Materials**	3			3	
MA 10	**Demolition waste reduction**	2			2	
MA11	**Construction waste reduction**	2			2	
	Total Credits	16	6	2	8	0
	Total RSI	5.82%	2.18%	0.73%	2.91%	0.00%

Notes: Wst: Waste, Mat: Material, Opt: Operational

The waste Reduction principle is the most desirable strategy in the waste hierarchy. Avoiding material waste from temporary works or over-design is possible when considered early during the project conception stage (Ferguson et al., 1995). BEAM Plus criteria include the reduction of material loss during construction - encouraging the use of ready-mixed mortar and concrete. BEAM Plus addresses waste reduction in temporary works with sustainably sourced timber criteria as well as encouraging formwork reuse as much as possible. BEAM Plus places the least focus on the Reduction principle; Wu et.al (2016) suggested that this method to control waste, for new residential green buildings, exists to motivate stakeholders to carry out waste reduction activities.

3.1.2 Criteria Related to Reuse

Reuse of existing building structures, components, or materials can lower the volume of waste entering the waste stream. BEAM Plus, considers building structure reuse, awarding two credits for excluding interior elements such as windows, doors, and other assemblies. Statistics show that 0% of assessed BEAM Plus platinum projects attempted the Building Reuse criteria (Ng, 2014). Poon and Jaillon (2002) suggested that building reuse might not be suitable for Hong Kong due to its limited space and high land prices, except in the case of historical preservation projects. Building reuse credits are not favorable in Hong Kong because redevelopment projects often gain a much greater plot ratio with new construction than with the strategy of building reuse. design for future deconstruction. Future deconstruction is a design phase consideration that provides opportunities for building components to be reused in the future. Because building material salvage relies on on-site sorting, designing for future deconstruction is perhaps a better solution to facilitate the Reuse principle. Waste sorting in CWM is a prerequisite in most rating tools including BEAM Plus. As prerequisites, which are compulsory for all projects, no credits are given for waste sorting and therefore are not reflected in the RSI.

3.1.3 Criteria Related to Recycle

Salvaging materials and structures for reuse and recycling is another aspect of waste minimization. Recycling is the principle that is adopted the least among the 3Rs In BEAM Plus, the minimum requirement for using recycled material is 10% by mass, volume, or cost. BEAM Plus specifies a minimum recycling rate of 30% and 60%. According to statistics from the Ng study (2014), the attempts at both recycled material and recycling rate credits in BEAM Plus platinum projects are very low.

3.1.4 Criteria Related to Disposal

Disposal is the least desirable principle and ranked at the bottom of the waste hierarchy model. Waste disposal: BEAM Plus prerequisite (MA3) requires on-site sorting of construction demolition waste (CDW) which must comply with certain public works guidelines.

3.2 Hong Kong BEAM Plus Case Study

A recently completed private residential development was selected as a case study (Table 1). In the case study, the following topics were assessed and discussed: (1) types of credits attempted under the Materials Aspects (MA) category of BEAM Plus; (2) measurable impact of the attempted MA credits on waste reduction; (3) achievability of MA credits.

3.2.1. Types of Credits Attempted Under MA

In this case study, the number and percentage of criteria attempted, within each performance category, were assessed. The category with the most attempted criteria is Site Aspects (SA), while the category with the least number of attempted criteria is MA with percentages of 87% and 64% respectively (Table 5). Among the remaining performance categories, percentages of attempted criteria are as follows: Energy Use (EU) (69%), Water Use (WU) (67%) and Indoor Environmental Quality (IEQ) (65%). The number of attempted credits (distinct from criteria) within each performance category was also assessed in this project. In this case study, EU is the category with the greatest number of attempted credits (93%), followed by SA (82%), IEQ (78%), and WU (67%). MA has the least number of attempted credits (41%). These findings are similar to the study by Ng (2013), which examined 12 Platinum projects (including 2 residential projects). In the BEAM Plus rating system, a project pursuing a gold rating must achieve 60% of the credits within the categories SA, EU and IEQ. However there are no minimum requirements for MA and WU. In addition, each performance category has its own weighting factor. After applying the weighting factors to the attempted credits of the case study, the value of attempted credits is as follows: SA 20%, MA 3%, EU 33%, WU 8% and IEQ 16% (Table 5). The weighting factors applied to the credits within each performance category (RSI using Eq.2) result in the following values per credit SA 1.14, MA 0.36, EU 0.83, WU 1.33, and IEQ 0.63 (Table 3). Thus,1 MA credit achieved has a value of only 0.36 of a credit gained in the final score.

The findings revealed that although the project attempted a similar percentage of criteria within MA, EU, WU, and IEQ, the MA credits attempted have a relatively lower value. However, the fact that there is no minimum threshold for MA may have contributed to the low number of criteria attempted. Although SA and MA both have a maximum number of 22 credits, the SA credits are worth 25% of the total, while the MA credits are worth 8%.

The attempted MA credits addressing (1) pollutants arising from manufacturing and transportation; and (2) waste generation and recycling were further examined. The criteria attempted: MA2 (Modular and standardized design), MA4 Adaptability and deconstruction, MA6 Sustainable forest products, MA7 Recycled materials, MA8 Ozone depleting substances, MA9 Regionally manufactured materials, and MA 11 Construction waste reduction (Table 6). According to the study by Ng (2013), the 3 most frequently attempted credits are MA8a, MA8b, and MA9. These credits were also attempted in this case study. MA8 and MA9 are related to reducing carbon emissions and ozone depletion. In addition, in the Ng study (2013), MA1a, MA1b, and MA5 were not attempted in all 12 platinum cases, and they were also not attempted in this case study (Table 6). MA1 is a criterion to encourage the reuse of existing building sub-structures or shells, and is the only criterion that addresses the Reuse principle. To reduce the extraction of natural resources, MA5 encourages the use of rapidly renewable materials. This reflects that the most frequently used MA credits are mainly related to pollution control. Although BEAM Plus has criteria related to waste, applicants have not frequently attempted those credits.

Table 5 - BEAM Plus maximum criteria and credits, and Project attempted criteria and credits

Category	SA			MA			EU			WU			IEQ			Overall		
	Max.	Proj.	%	Max.	Proj.	%	Max.	Proj.	%	Max.	Proj.	%	Max.	Proj.	%	Max.	Proj.	%
Criteria (Eq.5)	15	13	87 %	11	7	64 %	13	9	69 %	6	4	67 %	23	15	65 %	42	68	71 %
Credits (Eq.6)	22	18	82 %	22	9	41 %	42	39	93 %	9	6	67 %	32	25	78 %	95	72	NA
Credits attempted by weighting (weighting factor) (Eq.7)	20% (25%)			3% (/8%)			33% (/35%)			8% (/12%)			16% (/20%)			80% (/100%)		

Table 6 - Details of credits attempted in the Material Aspects category of BEAM Plus

Criteria		Credit Requirement	Credits	Attempted	Ranking of frequently used credits in Ng (2013)
MAP1	**Timber used for temporary works**	Virgin forest products are not used for temporary works during construction.	Y	Required	-
MAP2	**Use of non-cfc based refrigerants**	Using no chlorofluorocarbon (CFC)-based refrigerants in HVAC&R systems.	Y	Required	-
MAP3	**Construction/ demolition waste management plan**	Implementation of a waste management system that provides for the sorting, recycling and proper disposal of construction/ demolition materials.	Y	Required	-
MAP4	**Waste recycle facilities**	Provision of facilities for the collection, sorting, storage and disposal of waste and recovered materials.	Y	Required	-
MA1a	**Building reuse**	1 credit for the reuse of 30% or more of existing sub-structure or shell. 2 credits for the reuse of 60% or more of existing sub-structure or shell.	2	-	16*
MA1b		1 additional BONUS credit for use of 90% or more of existing sub-structure or shell.	1B	-	17*
MA2	**Modular and standardized design**	1 credit for demonstrating the application of modular and standardized design. +	1	1	9
MA3	**Prefabrication**	1 credit when the manufacture of 20% of listed prefabricated building elements has been off-site. + 2 credits where the manufacture of 40% of listed prefabricated building elements has been off-site.	2	-	13

MA4a	**Adaptability and deconstruction**	1 credit for designs providing spatial flexibility that can adapt spaces for different uses, and allows for expansion to permit additional spatial requirements to be 1 accommodated.	1	-	6
MA4b		1 credit for flexible design of services that can adapt to changes of layout and use.	1	-	7
MA4c		1 credit for designs providing flexibility through the choice of building structural system that allows for change in future use, and which is coordinated with interior planning modules.	1	1	5
MA5	**Rapidly renewable materials**	1 credit for demonstrating 2.5% of all building materials/products used in the project is rapidly renewable materials. + 2 credits where 5% of all building materials/products used in the project is rapidly renewable materials.	2	-	15*
MA6	**Sustainable forest products**	1 credit for demonstrating at least 50% of all timber and composite timber products used in the project are from sustainable source/recycled timber.	1	1	4
MA7a	**Recycled materials**	1 credit for use of recycled materials contributing to at least 10% of all materials used in site exterior surfacing work, structures and features.	1	-	8
MA7b		1 credit where at least 10% of all building materials used for facade and structural components are recycled materials.	1	1	11
MA7c		1 credit where at least 10% of all building materials used for interior non-structural components are recycled materials	1	-	14
MA8a	**Ozone depleting substances**	1 credit for using refrigerants with a value less than or equal to the threshold of the combined contribution to zone depletion and global warming potentials using the specified equation.	1	1	1
MA8b		1 credit for the use of products in the building fabric and services that avoids the use of ozone depleting substances in their manufacture, composition or use.	1	1	3
MA9	**Regionally manufactured materials**	1 credit for use of materials manufactured locally within 800km from the site, which contribute to at least 10% of all building materials used in the project. 2 credits for use of materials manufactured locally within 800km from the site, which contribute to at least 20% of all building materials used in the project.	2	2	2
MA10	**Demolition waste reduction**	1 credit for demonstrating that at least 30% of demolition waste is recycled. 2 credits for demonstrating that at least 60% of demolition waste is recycled.	2	-	12
MA11	**Construction waste reduction**	1 credit for demonstrating that at least 30% of construction waste is recycled. 2 credits for demonstration that at least 60% of construction waste is recycled. +	2	1	10

* Credits not attempted in the 12 platinum projects in Ng's study (2013)
+ Credits not commonly achieved in the 12 platinum projects in Ng's study (2013)

3.2.2 Achievability of Attempted MA Credits Addressing Waste

The case study attempted the following waste criteria addressing the Reduce principle: MA2 Modular and standardized design, MA3 Prefabrication, and MA4 Adaptability and deconstruction. The following waste criteria addressing the Reuse and Recycle principles were also attempted: MA1 Building reuse, MA6 Sustainable forest products, MA7 Recycled materials, MA10 Demolition waste reduction, and MA11 Construction waste reduction (Table 6). In MA, a total of 17 credits relate to waste (including 1 bonus credit from MA1).

In the case study, a total of nine MA credits were achieved – five of which are related to waste: MA2, MA4, MA6, MA7, and MA11 (Table 6). However, there are credits within certain criteria that cannot be achieved. Reasons were explained by the interviewee using waste hierarchy. Waste disposal was not included in the criteria.

3.2.2.1 Waste Reduction

To achieve the MA2 credit, the project must demonstrate that over 50% of the major elements are designed to be modular and standardized (Table 6). The interviewee explained that since a high-rise residential building is composed of floors that are typical with a large amount of repetition, it is possible to reach the 50% standardisation minimum. MA3 requires 20% or 40% of elements to be prefabricated. For typical residential buildings in Hong Kong, the facades are typically the only main elements that are prefabricated. Prefabrication or mass production is neither efficient nor common at the podium level. As shown in the drawings and data collected, the precast façades on typical floors comprise 15% (by volume) of the concrete built on a typical floor. According to the interviewee, 20% and 40% prefabrication calculated by weight or by volume is difficult to achieve. Moreover, there are reportedly numerous hindrances in using prefabrication; for example: need for frequent specification changes, lack of incentives, high overall cost, and lack of skilled labour (Jaillon et al., 2009) – which all contribute to the low adoption of prefabrication. As a result, it is difficult to meet MA3 prefabrication requirements. Credit MA4c, addressing structural adaptability, was also attempted (Table 6). This credit requires that 50% or more of the building's structural system is flexible enough to allow future changes of use and changes in interior planning modules. However, based on the explanation from the interviewee, MA4a spatial adaptability, and MA4b flexible engineering services require more space in order to provide the flexibility and multi-functional characteristics required. For a typical Hong Kong residential high-rise, real estate values require a tight fit and maximization. A loose fit design is a luxury not common in today's residential high-rise developments.

3.2.2.2 Waste Reuse

MA1 Building Reuse is a criterion encouraging the reuse of a building's existing sub-structure or shell. The interviewee explained that high-rise residential projects on previously developed land often involve an existing building structure that might not meet new design standards or developer demands (e.g. more units, or more gross floor area). For construction in new towns, vacant sites are common with no opportunities for existing building reuse. Thus, the interviewee claimed that building reuse was a decision made by the developer or architect.

3.2.2.3 Waste Recycled

MA6 Sustainable Forest Products is a credit that encourages using recycled timber to reduce demolition waste, or using timber from sustainable sources to protect forest ecology. Regarding achievability, the interviewee explained that there is a large amount of construction projects required to use sustainable timber and recycled timber. It is commonly found in the industry and thus, MA6 is considered achievable.

MA7 Recycled Materials includes credits that require 10% use of recycled materials: (1) outside surface works and structures, (2) building structure; and (3) interior components. Incorporating recycled content, as specified in BEAM Plus, is not typically considered in Hong Kong high-rise residential developments. Glass and steel comprise a large portion of materials used, and the fact that the recycled content criteria of BEAM Plus does not include these materials increases the difficulty to achieve this criteria. The interviewee mentioned that the manufacturers control the content of concrete, thus the contractor has little control over the recycled content of concrete mix. BEAM Plus specifies the method and units of measurement for calculating recycled content: (mass or volume) per dollar. The interviewee reflected that there is difficulty in calculating recycled materials because different materials are measured in different units (e.g. mass, volume, area). There is considerable effort in reconciling the units of all materials used into a common unit. In addition, if recycled content is calculated by cost, including the contractor's profit margin decreases the score, and excluding the margin impacts the contractor undesirably. In this case study, MA7b (which requires a minimum of 10% recycled content of materials used for façade and structural components) was attempted. According to Ng's study (2014), 65% of platinum projects (23 projects; 35% residential projects) were able to achieve the credit by using exterior paving works. Ng's study also indicated that more than 70% of projects used paving blocks and plastic timber made from recycled materials. MA7a and b are ranked 8 and 11 respectively (see Table 6 showing ranking of frequently used credits of projects from Ng's study (2013)). While MA7 credits are possible to achieve, they may not be attempted often due to the cost and time required to track and record the data.

MA10 Demolition Waste Reduction requires 30% or 60% of demolition waste to be recycled. MA10 was not considered because the site was vacant. However, in Ng's study (2014), more than 90% of projects recycled demolition waste. The Hong Kong Housing Authority's Green Construction (Housing Authority, 2016) efforts include encouraging Selective Demolition to increase the recycling rate of reusable materials. Selective Demolition involves removal and separation of recyclable materials on site prior to demolition. This process alters the typical construction demolition sequence. Credits awarded for demolition waste reduction are achievable if the site has an existing building.

MA11 Construction Waste Reduction requires that more than 30% or 60% of construction waste is recycled. As reported by the interviewee, it is hard to achieve 2 credits (60% construction waste recycled), due to (1) limited space on site for waste sorting and (2) few recycling companies; recycling waste has very low value and thus is not common.

3.2.3 Effectiveness of Attempted MA Credits to Reduce Waste

The case study project attempted the following five MA waste-related credits:

(1) MA2 Modular and Standardized Design: over 50% of building elements were designed as modular and standardised components – to minimise construction cut-off waste.

(2) MA4c Adaptability and Deconstruction: 50% or more of the structural design was designed for flexibility in future use – to reduce demolition waste from future changes.

(3) MA6 Sustainable Forest Products: 50% or more of timber and composite timber products were obtained from sustainable sources or recycled timber – to help reduce resource extraction and protect forest ecology.

(4) MA7b Recycled Materials: 10% or more of the building materials used in the façade and structural components were recycled materials – to encourage waste to be recycled and indirectly reduce waste disposal.

(5) MA11 Construction Waste Reduction: approximately 35% of construction waste was recycled – to help reduce disposal of construction waste.

According to the data collected, the waste generated from this project was 0.21 ton/m^2 (all construction waste generated per constructed floor area (CFA)). Data from Jaillon et al. (2009), showed that the quantity of waste generated per CFA for high-rise residential buildings in the private sector was 0.23 ton/m^2 when using prefabrication techniques, and 0.30 ton/m^2 when using conventional techniques (Table 7). In comparison, this project's construction waste was 8.7% lower than projects from Jaillon et al., using prefabrication techniques, and 30% lower than projects from Jaillon et al. (2009), using conventional techniques. According to data collected from the interviewee, recycled waste is mainly: steel (95.5%), and paper/cardboard packaging (4.4%). Steel formwork is reused on typical floors; while timber formwork is reused only two to three times.

MA P1, avoiding the use of virgin timber for temporary works, MA P3 providing a construction/demolition waste management plan, and MA P4 providing waste recycling facilities are all related to waste and were also attempted in the case study project as they are BEAM Plus prerequisites. MA P1 is a requirement similar to MA6 whereby they both encourage contractors to use timber from well-managed sources or use recycled timber – to indirectly reduce waste disposal to landfill. MA P3 requires a planning proposal for managing waste – written by the contractor, which is the only strategy related to disposal in BEAM Plus as mentioned in the previous finding. It is a criterion to encourage sorting, recycling and disposal of construction waste in best practice construction waste management (CWM). However, according to the description from the interviewee, CWM was difficult as the vacant site was very limited in space, the vehicle path and storage area for materials left little room for waste sorting. Moreover, there may not have been recycling companies to collect the waste due to; (1) low profit for recycling certain materials, for example paper and plastic, and; (2) company size which may not have been able to collect huge amounts of waste and; (3) the high risk to collect large amounts of waste: lack of a recycling industry, and the possibility that recycled waste would become real trash if no one was willing to purchase it.

The ability to quantify the effectiveness of construction waste criteria is difficult because: there are constraints in proper waste sorting and recycling, there is a low percentage of adopting prefabrication on typical repetitive floors, and the impact of some credits (MA4c design for structural flexibility for future changes, MA6 use of timber that is recycled or from sustainable sources, and MA7b use of recycled materials for the façade and structural components) is not reflected immediately within the construction and demolition stages. In addition, the reduction of construction waste might due to the increase of using metal formwork. According to the Poon et al. study (2004), timber formwork was the main contributor to waste generation; and replacing timber formwork with metal formwork could reduce this waste. Moreover, curtain walls, used in this project, were not used in the case studies in the Jaillon et al. study (2009); this may also affect the quantity of waste generated. In 2006, the Construction Waste Disposal Charging Scheme was implemented in Hong Kong to impose charges on construction and demolition waste disposal to landfill. It would be one of the reasons of reducing the waste quality compared with previous projects. However, according to the study from Yu et al. (2013), it had little impact on reducing waste. Taking into account the scenarios above, applying BEAM Plus criteria, did not significantly reduce waste.

Table 7 - Comparison of this case study and other residential projects studied from Jaillon, Poon and Chiang (2009)

	Case study	4 Projects using prefabrication techniques (Jaillon, Poon and Chiang, 2009)	4 Projects using conventional techniques (Jaillon, Poon and Chiang, 2009)
Completion year	2015	2003-2004	2002-2003
Building technologies			
Metal formworks (%)	90%	72%	0%
Timber formworks (%)	10%	28%	100%
Prefabricated elements	Precast façade Curtain Wall	Precast façade Precast stairs *Semi-precast slab *Lost form panel (permanent formwork) *Semi-precast balcony	NA
Waste quantity/CFA (ton/m^2)	0.21	0.23	0.30
Waste reduction level (%)	-30%	-23%	100%

*prefabricated elements used in some of the projects

3.3 Lessons for Hong Kong

In BEAM Plus, there are no minimum thresholds in the MA performance category. Hong Kong regulations promote the adoption of BEAM Plus by incentivising the developer with GFA concessions – a financial gain. Lau (2013) discussed BEAM Plus weaknesses including the low number of prerequisites for registered projects, and the unbalanced scorecards (no thresholds for either the materials or water categories). Regarding CWM, Lau (2013) also suggested that BEAM Plus Materials Aspects encourage the adoption of recyclable materials and promote the reuse of temporary site elements as permanent building elements.

4. Conclusion

In Hong Kong, the landfill shortage crisis has created a significant construction waste issue. In this paper, a comparison of five selected green building rating tools was conducted to investigate CWM criteria, together with a Hong Kong BEAM Plus case study project.

BEAM Plus concerns least on this, which is contradictory to the actual situation in Hong Kong, where construction waste is an urgent issue. In terms of the 3R principles, the comparison told that Hong Kong lacks concerns on the principle of Reduction and Reuse. The results are further examined with a Hong Kong based case.

The case study analysis reflects that:

(1) The reasons BEAM Plus MA credits are not commonly attempted are not only due to the lack of a minimum threshold, but also due to a low weighting. The weighting of MA credits is extremely low when compared to the weighting of other performance categories. The MA category has an 8% value; 1 MA credit achieved is worth only 0.36 of a credit in the Overall Assessment Grade.

(2) Some of the credits are difficult to achieve: MA 1 Building Reuse is limited as incorporating existing building structures is less desirable and more complicated for most developers, or if the site is vacant; MA 3 Prefabrication requires a percentage of prefabrication that is higher than typical high-rise residential projects in Hong Kong and; MA 11 Recycling Construction Waste is a challenge due to limited sorting space on small sites and lack of recycling companies to receive sorted waste.

(3) In this case study, waste generated per CFA was 0.21 (ton/m^2), which is an 8% reduction compared to projects using prefabrication in 2003-2004, and a 30% reduction compared to conventional projects. This is partly due to MA2 Modular and standardized design and MA11 Recycling construction waste, which are both directly related to construction waste reduction. In addition to applying BEAM Plus criteria, the increased use of metal formwork, increased use of curtain walls, and levying waste charges in 2006, all contributed to waste reduction. Although 8 out of 11 MA criteria are waste-related, the MA performance category shows a limited effectiveness on waste reduction.

(4) In conclusion, MA criteria are not commonly attempted due to low weighting, lack of required minimum thresholds, and difficulty of achieving credits. Considering the importance of addressing the waste generation problem,

adjusting the weighting factor of MA criteria is recommended. While reducing waste is an MA objective, the current achievability and effectiveness of waste-related credits is low.

5. Recommendations

Insights gained, from other rating tools, regarding the Reduction, Reuse and Recycle principles, include: proposing a waste reduction rate (recycling or waste diversion) to be maintained from design through the construction process; and encouraging design for future reuse of building structures and components.

In future research, the effectiveness of BEAM Plus to reduce construction waste can be further studied through survey and interviews. Moreover, it is necessary to revisit the impact, achievability, and weight of each waste-related credit to improve effectiveness of waste reduction efforts. This paper, through assessment and comparison, has highlighted the differences in CWM practices between BEAM Plus and four other selected green building rating tools. This study can hopefully contribute to the future improvement of waste reduction strategies of BEAM Plus with the goal of reducing pressure on Hong Kong landfill sites and creating a more sustainable city.

Furthermore, the experience and lessons for Hong Kong could also become indications and basis for the environmental rating tools from other countries. Further examination and assessment of them could be done upon their requests. Besides, future research could study the construction efficiency and effectiveness upon the CWM significance studied here.

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