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CONSTRUCTION INDUSTRY COUNCIL 建造業議會

HKGBC 香港綠色建築議會

Green Design Guide

for Material Resources Optimisation in Building Life Cycle

Green Design Guide for Material Resources Optimisation in Building Cycle

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HKGBC
香港綠色建築議會

About HKGBC

The Hong Kong Green Building Council Limited (HKGBC) is a non-profit, member led organisation established in 2009 with the vision to help save the planet and improve the wellbeing of the people of Hong Kong by transforming the city into a greener built environment. The Founding Members of HKGBC include the Construction Industry Council (CIC), the Business Environment Council (BEC), the BEAM Society Limited (BSL) and the Professional Green Building Council (PGBC). Its mission is to lead market transformation by advocating green policies to the Government; introducing green building practices to all stakeholders; setting design, construction and management standards for the building profession; and promoting green living to the people of Hong Kong.

To learn more about the HKGBC, please visit *www.hkgbc.org.hk.*

Our Vision

To help save the planet and improve the wellbeing of the people of Hong Kong by transforming the city into a greener built environment.

Our Mission

To lead market transformation by advocating green policies to the Government; introducing green building practices to all stakeholders; setting design, construction and management standards for the building profession; and promoting green living to the people of Hong Kong.

Content

Message from
Secretary for the Environment

Waste generated from construction activity is always an issue of concern in Hong Kong as it uses up a good part of our landfill space. Construction waste is the second largest category of the total solid waste disposed of at landfills. Any reduction in construction waste helps to mitigate the waste challenge in Hong Kong.

There has been a marked decrease by about 50% in the disposal of construction waste at landfills since the implementation of the Construction Waste Disposal Charging Scheme in 2006. But with the latest figures in 2016 sitting at over 4,000 tonnes per day, we cannot afford to spare any effort in reducing and separating construction waste at source through careful planning and design during early stages of construction projects and diligent site work control.

The Green Design Guide for Material Resources Optimisation in Building Life Cycle, introduced by the Hong Kong Green Building Council (HKGBC), puts forward guidelines and strategies to help industry practitioners plan for construction waste reduction throughout the whole building life cycle during planning and design stages.

I wish to express my appreciation to the HKGBC for their efforts in promoting a sustainable built environment in Hong Kong. The Government is pressing ahead with the implementation of Hong Kong Blueprint for Sustainable Use of Resources 2013 – 2022 and with the collective efforts of the Government, stakeholders and the community at large, steady progress has been made on all fronts. HKGBC's Green Design Guide for Material Resources Optimisation in Building Life Cycle is a valuable contribution and indeed a timely complement to the Government's initiatives on promoting sustainable development.

Mr WONG Kam-sing, GBS, JP
Secretary for the Environment

Foreword from
Chairman of HKGBC

On behalf of the Hong Kong Green Building Council (HKGBC), I take great pleasure in presenting to the building industry and the general public the Green Design Guide for Material Resources Optimisation in Building Life Cycle (the Guidebook).

Founded in 2009, the HKGBC is committed to providing guidebooks on building design, construction and management good practices for promoting green building and living in Hong Kong. Over the years, a number of guidebooks have been published for different types of buildings, covering schools, shops and offices, etc. To minimise building material waste and enhance public awareness on waste problem and management, HKGBC now presents its sixth guidebook of good design practices on the subject.

The Guidebook encourages the building professionals and contractors to take into consideration building material waste reduction during planning and design stages, and to adopt green designs for construction, operation, maintenance, and eventual demolition.

We would like to take this opportunity to express our sincere appreciation to the HKGBC's Task Force on Green Design Guide for their contribution to the development of the Guidebook. Our heartfelt gratitude also goes to organisations who have shared with us their success stories and valuable advice when compiling the Guidebook.

Finally, we would like to thank the Construction Industry Council (CIC) for its professional and funding support to this project.

We hope the Guidebook will provide practical guidance and inspiration to the building industry. Recognising the pressing need to minimise building material waste, it is now the time for every one of us to make a joint effort to create of a more sustainable environment. I am sure through our concerted effort we can build a greener Hong Kong.

Mr CHEUNG Hau-wai, SBS
Chairman, Hong Kong Green Building Council

Executive Summary

According to the statistics released by the Environmental Protection Department (EPD), HKSAR in 2016, waste in construction sites remains the second largest category of the total solid waste disposed of at landfills. As a driver to advance the development of green buildings in Hong Kong, the Hong Kong Green Building Council (HKGBC) aims to reduce the building material waste in order to confront the tough situation that our landfills are facing through this Guide. The aim of this Guide is to alert the public and building professionals about the building material waste problem and provide adequate guidelines during planning and design stages in minimising building material waste for the Hong Kong building industry.

The introduction chapter of the Guide briefly defines building material waste and the need of conducting the study. Following chapters are arranged in the order of a building life cycle. The second chapter introduces how Business Process Reengineering (BPR) could be adopted in Integrated Design Process (IDP). The chapter also studies how Building Information Modelling (BIM) and IDP could work together to reduce building material waste when designing a building. Chapter 3 demonstrates construction techniques to be considered to enhance efficiency of construction and minimise building material waste. The followed chapter presents options on how a building could be designed to accommodate future changes and to reduce renovation waste throughout the occupation period. Chapter 5 provides insights on the concept of "Design for Demolition" including careful planning of deconstruction, reusing and recycling disassembled materials. The final chapter concludes this Guide by providing recommendations on reducing building material waste for the entire building life cycle when designing the building.

Chapter 1 Introduction

Definition of building material and building material waste

BUILDING MATERIAL is any substance, matter or thing which is used for construction of building, building services and facilities during the building life cycle. Any remaining of building material which is not able to be used during the building life cycle is defined as *BUILDING MATERIAL WASTE* in this study and is equivalent to Construction and Demolition (C&D) waste.

Building material waste is categorised as following types:

- Inert waste (also known as "public fill")
- Non-inert waste
- 3R materials (Reduce, Reuse, Recycle)

Figure 1 Classification of building material waste

BUILDING MATERIAL WASTE MANAGEMENT FLOW IN HONG KONG

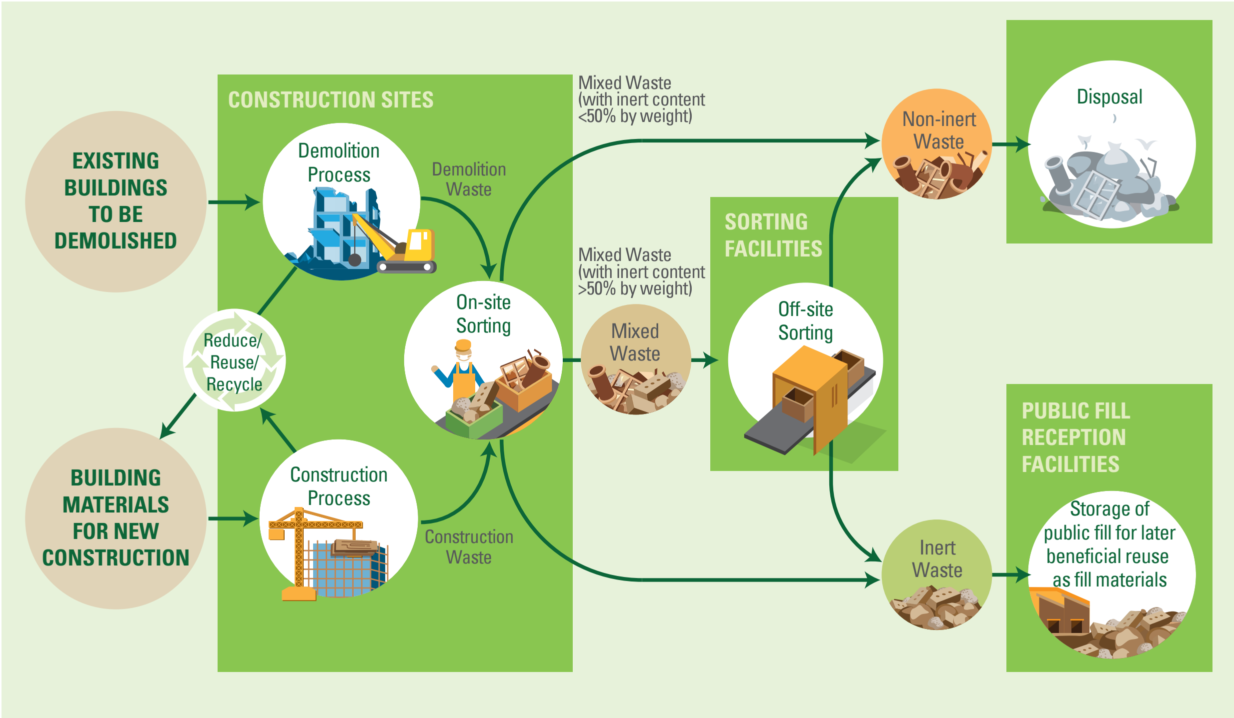


Figure 2 Typical building material waste management flow

The aim of this Guide is to inform the public and building professionals about the building material waste problem and provide adequate technical guidelines in optimising the use of building materials for the Hong Kong building industry.

Government and Organisations
To promote the importance of building material waste minimisation to the industry and provide professional trainings to related sectors.

Developers
To take lead and encourage the adoption of building material waste minimisation strategies in a project and be aware of the associating financial benefits / cost.

Facility Management
To advise on how building material waste could be reduced during the operation and maintenance stage of buildings.

Design Team
To incorporate innovative sustainable designs to minimise building material waste at the very beginning of a project.

Contractors
To implement mitigation measures to reduce building material waste, address problems arising from the waste materials and ensure good waste management practices during construction.

Figure 3 Practitioners' roles on minimisation of building material waste

The following chapters will be arranged in the order of a building life cycle:

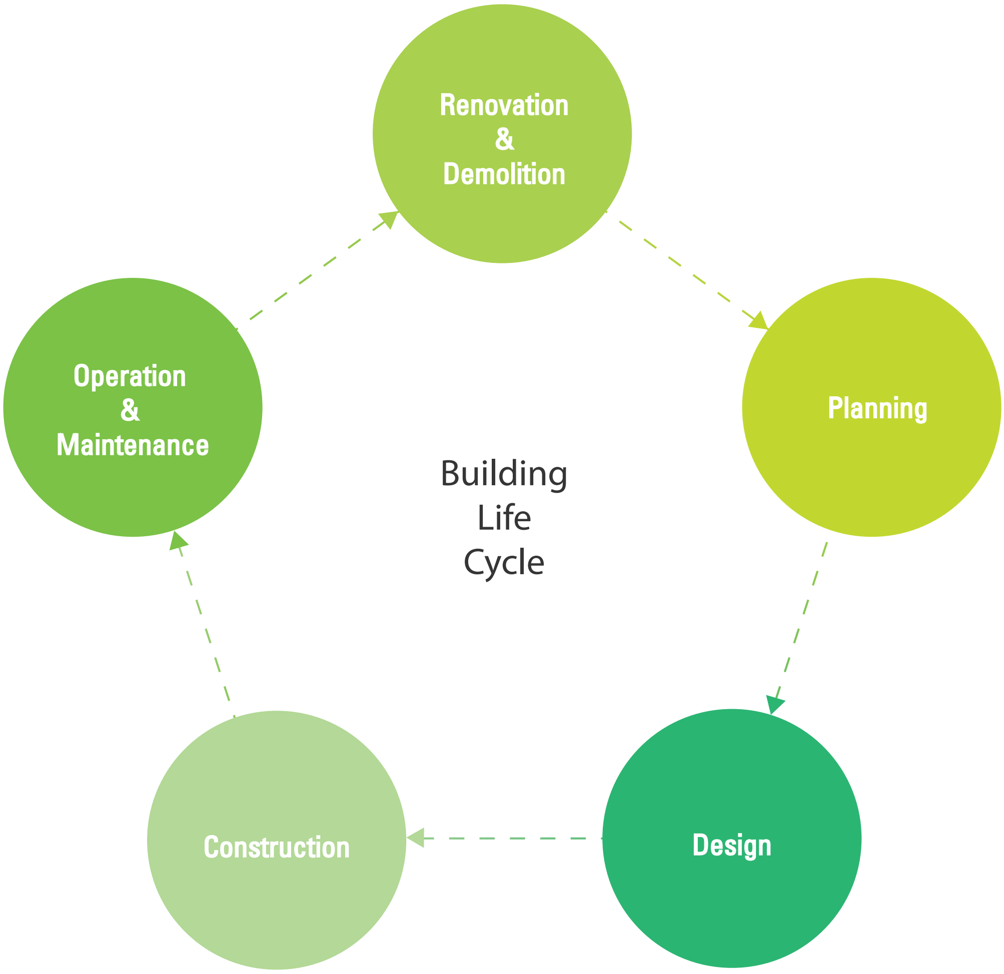
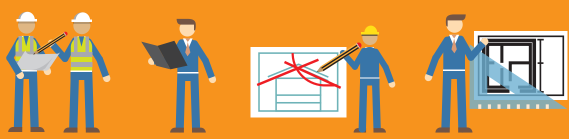


Figure 4 Building life cycle



Chapter 2
Integrated Design

A GOOD BUILDING DESIGN NOT ONLY LOOKS GOOD, ENHANCE COMFORT AND FLEXIBILITY, AND BE PRACTICAL AND USEFUL. In modern days, architects and designers need to take environmental protection into account to reduce waste production and carbon emission from the design stage to future management and maintenance.

Building material waste minimisation can commence as early as in the design stage since the source of waste are related to design changes, leftover material scraps, design or detailing errors. Building Information Modelling (BIM) and Integrated Design Process (IDP) are two crucial concepts in building material waste minimisation. Their relationships with Business Process Reengineering (BPR) are also explored in this chapter.

Business Process Reengineering (BPR) 2.1

Business Process Reengineering (BPR) is defined by Hammer and Champy as "the fundamental reconsideration and radical redesign of organisational processes, in order to achieve drastic improvement of current performance in cost, service and speed". The concept is in contrast with Kaizen method – a management concept for incremental change [Bogdănoiu, 2009].

Information technology plays a major role in BPR. This is because it provides office automation, allows business to be conducted in different locations, provides flexibility in manufacturing, permits quicker delivery to customers and supports rapid and paperless transactions [Nesrine & Habib, 2013]. One of the information technologies being frequently used in building projects is BIM which would be further elaborated in following chapters.
As Kaizen method indicates a system of continuous improvement in quality, technology, processes, company culture, productivity, safety and leadership. BPR in a building project is usually led by consultants, top management, and a cross-functional project team, involves changes in structures and in processes within the business environment. The entire technological, human, and organisational dimensions may be changed. Reengineering seeks breakthroughs, not by enhancing existing processes, but by discarding them and replacing them with entirely new ones. In the case of a building project, the idea of BPR is commonly adopted in IDP.

Generally, business is characterised by three elements – inputs, processing and outcomes. Processing is a problematic part while BPR mainly intervenes in this part, making it becomes less time and money consuming [Bogdănoiu, 2009].

BPR consists of three key components – redesign, retool and reorchestrate [Bogdănoiu, 2009]. Figure 5 demonstrates the key concepts of BPR.

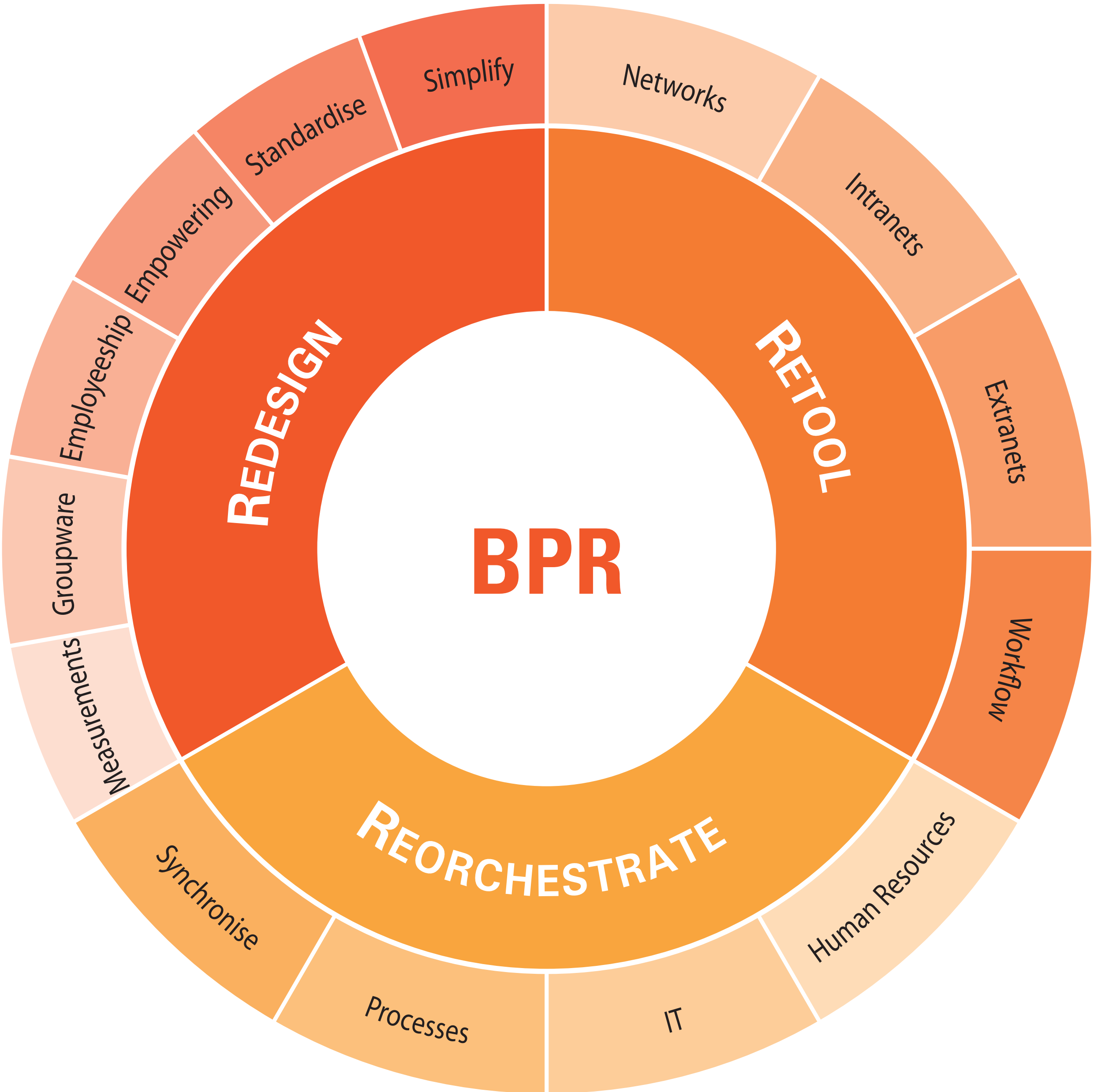
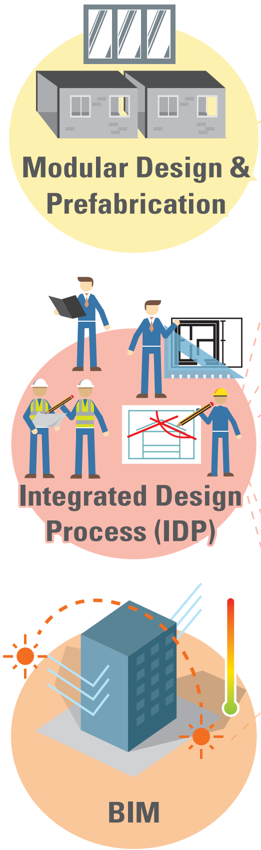


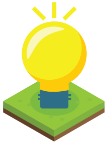
Figure 5 The 3Rs of reengineering and their key concepts

To implement BPR, the following key actions need to take place:



1. Selection of the strategic (value-adding) processes for redesign
2. Simplify new processes - minimise steps - optimise efficiency – modelling
3. Organise a team of employees for each process and assign a role for process coordinator
4. Organise the workflow - document transfer and control
5. Assign responsibilities and roles for each process
6. Automate processes using IT (Intranets, Extranets, Workflow Management)
7. Train the process team to efficiently manage and operate the new process
8. Introduce the redesigned process into the business organisational structure

2.2 Building Information Modelling (BIM)



Building Information Modelling (BIM) is not just a 3D model-based architectural drawing tool but a modern technology to use, reuse and exchange information to facilitate project management and execution from planning to design, construction and operations.

The origins of large amounts of waste in construction sites are related to unexpected design changes, poor procurement and planning, leftover material scraps, design or detailing errors. BIM permeates into the major generation source of waste and eliminates the non-value adding activities that are not consistent or necessary [Ahankoob, Khoshnava & Preece, 2012]. A study carried out by Cheng, Won and Das (2015) indicated that total volume of building material waste from demolition based on the traditional way was 15.8 percent different from the result using BIM.

As illustrated in Figure 6, BIM technology can be adopted throughout the building life cycle from design, build to operation. It enables better control of the construction process and enhance cross-disciplinary collaboration, problem solving, decision making and risk management. The tool equips project members including building owners, contractors, architects and engineers with the insight and tools to more efficiently plan, design, construct, and manage buildings and infrastructure.

BIM could be adopted throughout the building life cycle

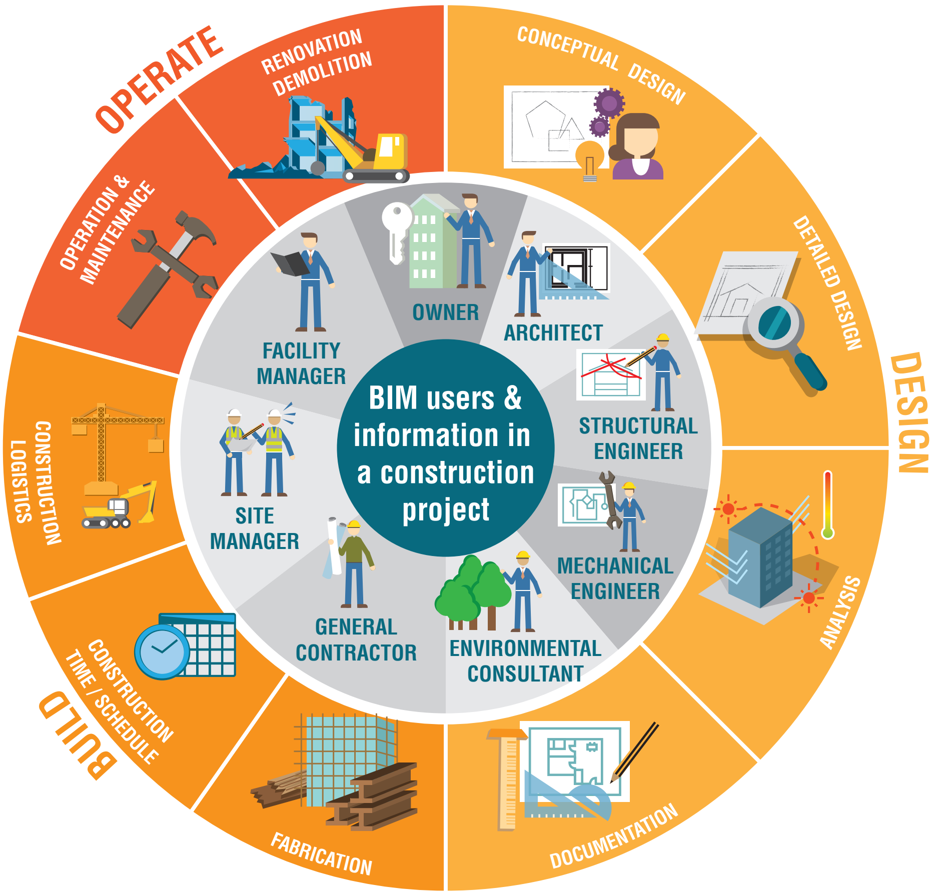


Figure 6 BIM users and project life cycle

Further than the development of initial ideas (1D) and layout plans (2D), 3D BIM refers to the visualisation of three spatial dimensions of a building model, namely, the width, length and height.

When the scope of 3D BIM extends beyond to 4D BIM (3D+Time), it is used for construction site planning related activities such as scheduling, project phasing, time lining, material ordering, fabrication, and delivery of all building components [Simeone, Schaumann, Kalay & Carrara, 2013]. It allows participants to extract and manage the progress of construction activities, visualise site status information, evaluate change impact and optimise team coordination. Precise programme scheduling enables just-in-time delivery of materials and equipment, reducing potential on-site damages. Designers and managers can pinpoint potential issues before becoming problematic. The utilisation of 4D BIM can result in improved controls over conflict detection or over the complexity of changes occurring.

5D BIM (4D+Cost), on the other hand, is used for budget tracking and cost related activities. 5D BIM integrates design with estimating materials and scheduling labour. The association with 3D and 4D allows participants to visualise the progress of their activities and related costs over the period. The incorporation of waste management plan to the 4D BIM could potentially reduce waste therefore cut down costs. This results in greater accuracy and predictability of project's estimations through evaluating scenarios, analysing the type and amount of materials will be required during a certain construction phase.

6D BIM (5D+Operation & Maintenance) is the linking of attribute data to support facilities management and building operation, including monitoring the building performance, data logging, tracking maintenance schedule, etc. Integrating 6D BIM with Building Management Systems (BMS) enables all aspects of project life cycle management information to be visualised by building operators (e.g. facility managers, property managers, etc.). The "As-Built" BIM model with building component information such as product specifications and warranties, manufacturer information and contacts, maintenance/operation manuals, photos, etc. would be accessible to the building operators through a customised web-based platform. This is intended to aid facility managers in the operation and maintenance of the facilities [Simeone et al., 2013]. BIM for Operation & Maintenance will be further elaborated in Chapter 4.

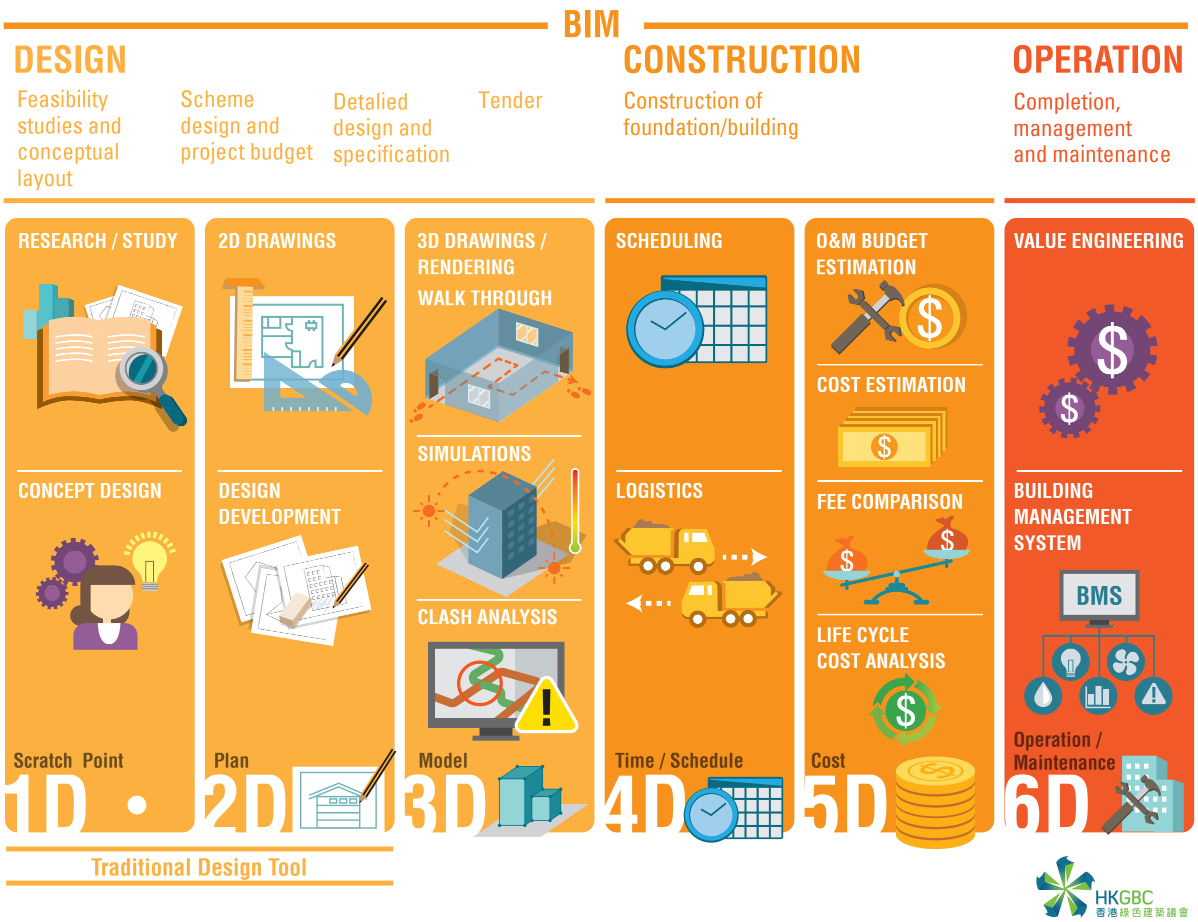


Figure 7 Capability of 6-dimensional BIM

A BIM model not only enables project participants to visualise the building in three-dimensions, it also stores data and updates them along the project life cycle from the earliest conception to demolition. One of the most notable benefits of BIM is the savings associated with eliminating inaccuracies, redundancies, and waste generated from conventional building practices. It can reveal potential design problems in early stage so that coordination among the design team can occur sooner rather than later to resolve the issues.

Benefits of using BIM are illustrated in Figure 8 below.

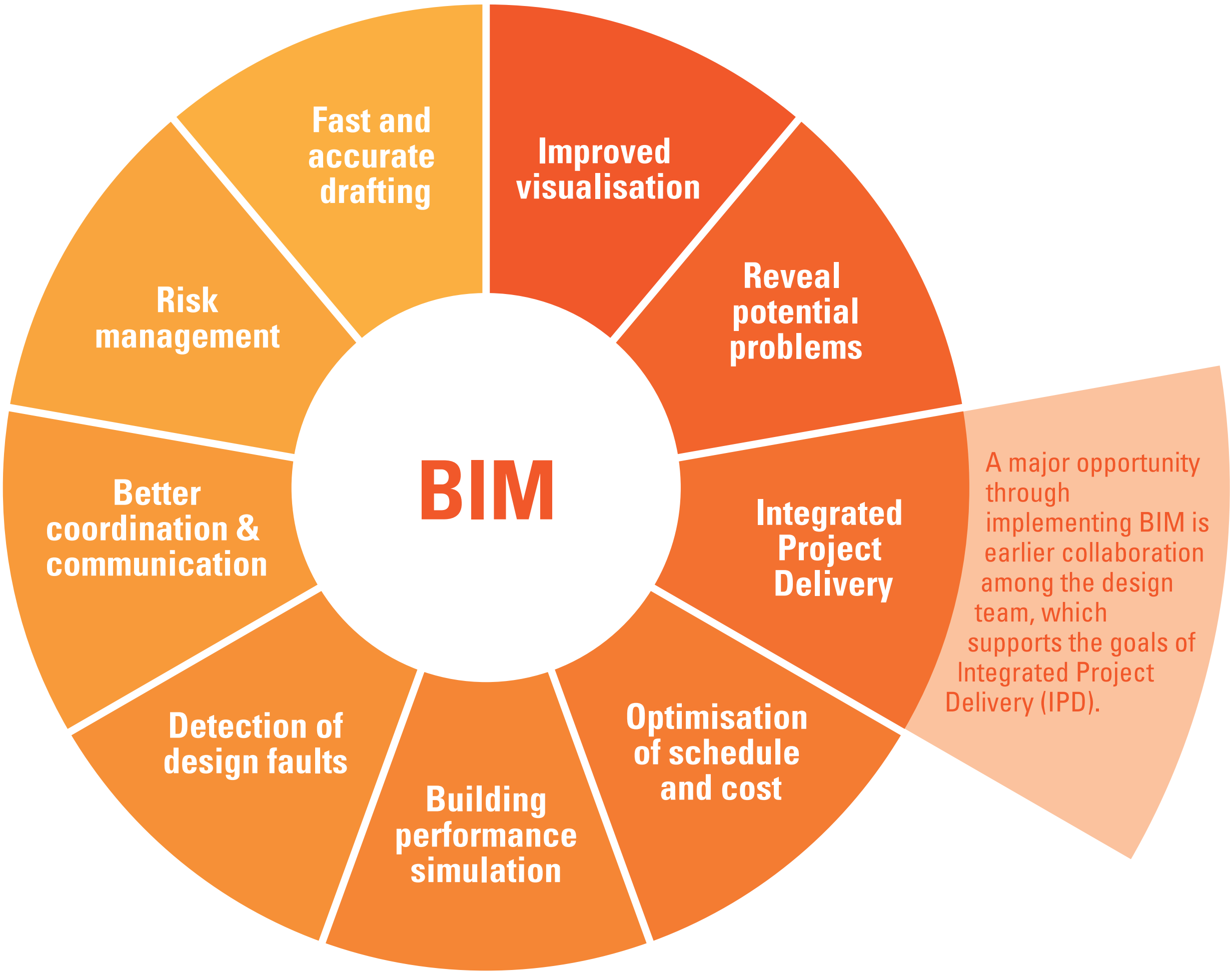


Figure 8 Benefits of BIM

It is important yet difficult to accurately estimate the amount of materials required on a construction site in order to reduce unnecessary raw materials and improve a procurement process. BIM is known as a tool that helps contractors and subcontractors to plan better in terms of scheduling, logistics and materials estimations. It also helps to produce result faster, and to finish projects on budget. A BIM model can be used to precisely perform quantity take-off in the design and construction processes which prevents the amount of over-production generating unnecessary materials. BIM-based quantity take-off can explore different design options and concepts by considering the perspective of building material waste management [Cheng, Won & Das, 2015].

Referring to a study carried out by the Construction Industry Council (CIC) in 2014, one of the driving forces for the adoption of BIM would be cost saving and reduction in construction waste. BIM contributes in inspecting for all interferences, clashes and collision by visual technology and thus reduce design faults. This could be achieved by using BIM to check for structural, architectural and building services clashes. By using traditional methods (e.g. 2D drawings), most of these errors are detected only after the work has been started, which might lead to site conflicts and require rework.

However, BIM can tackle these issues. Stanford University Centre for Integrated Facilities Engineering (CIFE) surveyed that, BIM provides an estimated 40 percent reduction in unbudgeted changes, results in contract savings up to 10 percent with the use of clash detection, and reduces project time by 7 percent [Gilligan & Kunz, 2007]. The strength of BIM makes it as an advisory tool for designers and engineers.

This is in contrast with traditional design workflows, such as design-bid-build or the use of traditional design tools. The problem with this traditional workflow is that conflict resolution and design changes tend to happen later in the project timeline, which has far less impact on the effectiveness of the design changes than making the same changes early in the timeline. A major opportunity through implementing BIM is earlier collaboration among the design team, which supports the goals of Integrated Design Process (IDP).

Moreover, adopting BIM with design team members could obtain 1 credit from BEAM Plus for New Buildings Version 1.2. Three bonus credits are also available for using BIM among design teams and contractors, BIM for schedules preparation and tracking budget, BIM for facility management use.

There is a rising number of governmental and commercial organisations mandating the use of BIM in building projects, for example, the Hong Kong Housing Authority (HKHA). HKHA has introduced BIM in its development of public rental housing projects since 2006. They have used BIM for design visualisation and progressively carried forward to subsequent stages to benefit the chain of stakeholders along the building life cycle. Through pilot and actual implementation of BIM in their projects, the quality of buildings were improved by optimising designs, improving coordination and reducing building material waste.

2.3 Integrated Design Process (IDP)

Technological advancement along with owners' ongoing demand for more effective processes that result in better, faster, less costly and less adversarial building projects are driving significant and rapid change in the building industry.

"The Integrated Design Process (IDP) is a method for realising high performance buildings that contribute to sustainable communities. It is a collaborative process that focuses on the design, construction, operation and occupancy of a building over its complete life cycle. The IDP is designed to allow the client and other stakeholders to develop and realise clearly defined and challenging functional, environmental and economic goals and objectives." (Larsson, 2002)

In general, IDP is a method used for the design and operation of built environment that seeks to achieve high performance on a wide variety of well-defined environmental and social goals while staying within budgetary and scheduling constraints. It relies upon a multi-disciplinary and collaborative team from the design phase to construction to the actual day-to-day operation, together right from the start to collaborate. To deliver a better outcome, IDP involves all people from designers to end users to establish scope, budget and other objectives.

As shown in Figure 9, typical organisation chart for conventional design project in which the client's primary contacts are architect and contractor, where architect coordinates with other professionals in a linear structure. When decision making is hierarchical, it often results in targeting blame when issues arise. In order to streamline project delivery and ensure quality and efficiency, having all parties to share in the responsibility is crucial.

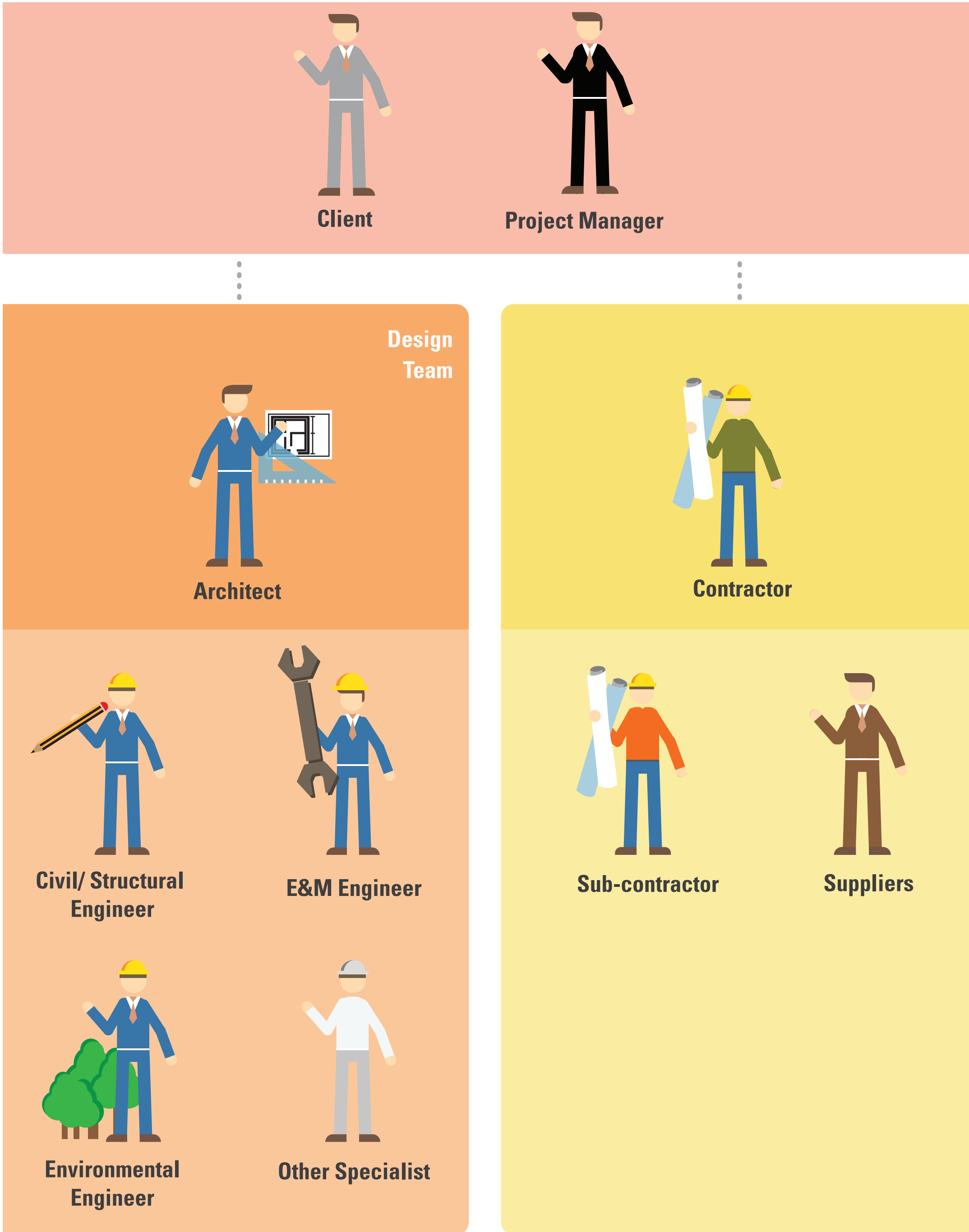


Figure 9 Organisation chart for a conventional design project

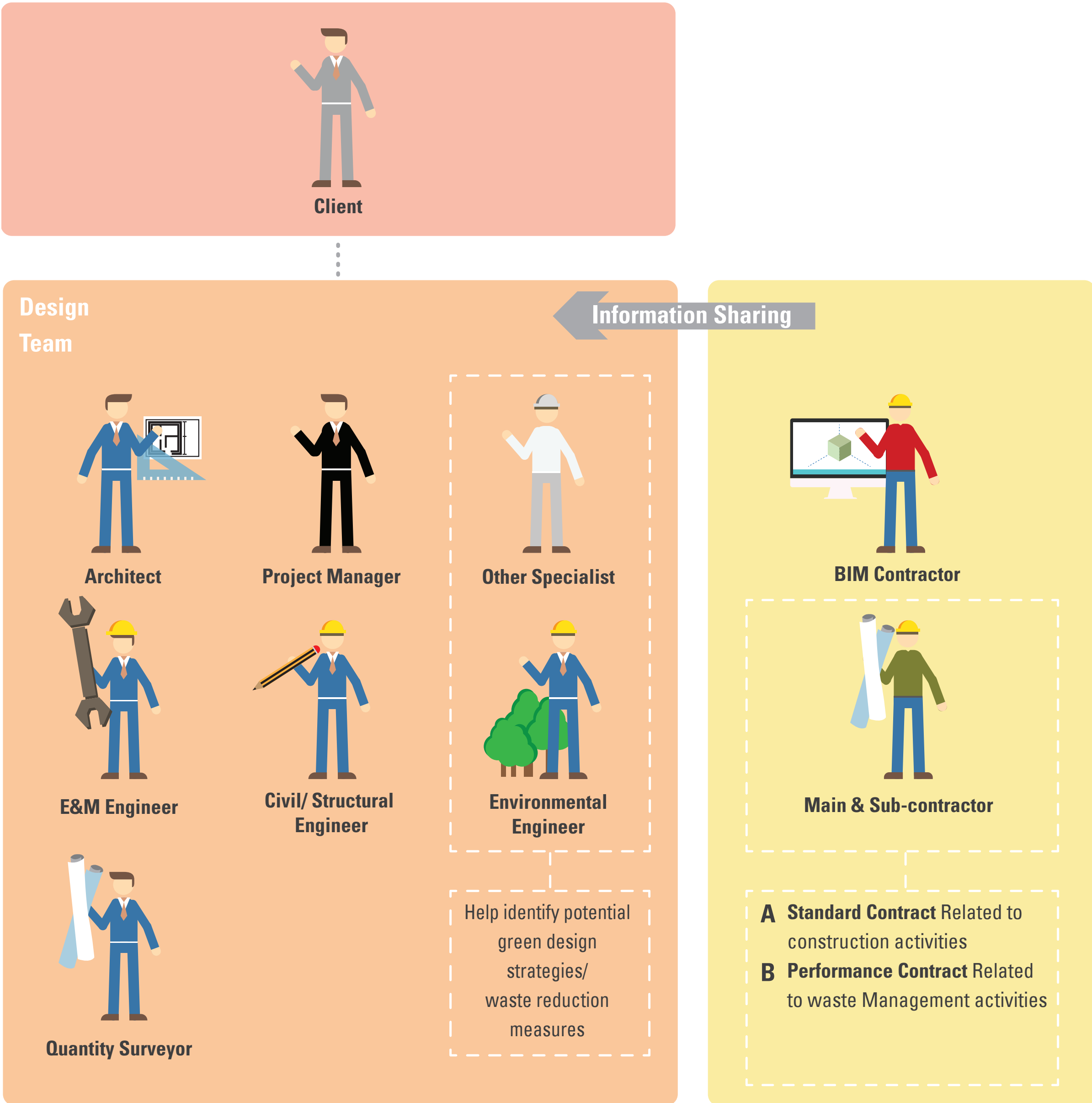


Figure 10 Organisation chart for IDP

IDP requires the construction team, specialists, owner, developers and facility management to fully participate in early stages with free flow of information so that it could reduce the cost of design changes. A typical organisation chart for IDP is shown in Figure 10 where core team is expanded to include the contractor, project manager and representatives of facility management team. IDP is built on collaboration, which in turn is built on trust. Effectively structured, trust-based collaboration encourages parties to focus on project outcomes rather than their individual goals [The American Institute of Architects, 2007]. The core team is more closely interlinked with support from consultants and other specialists when needed. Relationship within the IDP structure is a shared risk/rewards model where all parties are equally vested. This is in the best interest of all parties to set up goals and solve problem efficiently, for example, the adoption of green materials.

HKGBC Green Product Accreditation and Standards (HK G-PASS) initiated by the HKGBC aims to devise a Hong Kong based labelling scheme to certify environmentally friendly building material, products and building services components. The scheme covers 25 product categories, providing consumers, industry stakeholders and policy makers with a list of robustly assessed and certified green building products, the Scheme helps stimulate both supply and demand for greener building material and products.

Benefits for different parties for adopting IDP in a building project are listed in Figure 11 below [The American Institute of Architects, 2007].

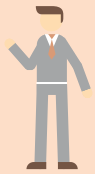
PARTY	BENEFITS
 **Client**	• **Effectively balance project options to meet their business enterprise goals** • **Reduce cost / waste** • **Maintain schedule and enhance quality and sustainability**
 **Contractor**	• **Improve cost control and budget management to increase the likelihood of achieving project goals, including schedule, life cycle costs, quality and sustainability** • **Assist the establishment of waste reduction plans** • **Discover opportunities for price reduction strategies** • **Optimise material use and logistics** • **Waste management in terms of resource conservation and on-site recycling** • **Avoid over ordering of materials and use of incorrect products**
 **Design Team**	• **Offer pre-construction resolution of design-related issues resulting in improved project quality and financial performance.** • **Work together concurrently as strategies emerge**
 **Facility Manager**	• **Reduce major repairs and alterations in the lifespan of the facility** • **Provide feedback about how occupants might react to certain design features** • **Offer recommendations for optimising building operation and maintenance.** • **Provide plans on reuse/recycle building material waste generated from fitting out works, etc.**

Figure 11 Benefits of IDP for client, constructor, design team and facility manager

IDP is in contrast with the traditional process when the flow of decision making is not hierarchical, it is more likely that multiple parties can come up with optimal solutions. In terms of efficiency flow of decision making, all major parties are involved in the meetings for the duration of the project which minimise the decision making timeline and issues could be dealt with in early stage. Team members of IDP can be more than traditional project delivery. Apart from owners, architects, and contractors, integrated projects are uniquely distinguished by highly effective collaboration among the owner, the prime designer, and the prime constructor, commencing at early design and continuing through to project handover.

The implementation of collaboration among all parties from the primary stage of development is a key component in the IDP. One important difference is the presence of the owner/developer and representatives from property/facility management as a team member at pre-design stage as integration design is often an owner-driven process where owners are usually influential members of the design process. This ensures the owner's commitment to design decisions which need to be made at early stage, including green measures and waste reduction plans. In IDP, the architect takes the role as an educator. For example, if waste reduction goals are not established, the architect will have to educate the team about those benefits.

Involving a contractor in early design stage will definitely assist the establishment of waste reduction/environmental plans, as during the design process, contractor can identify requirements and expectations relate to the construction activities, thus contribute to the overall planning on how to achieve a waste reduction goal. This may also discover opportunities for price reduction strategies and how their goals can be achieved in optimising material use and logistics, by waste management in terms of resource conservation and on-site recycling. This can also avoid over ordering of materials and use of incorrect products. Contractors could also help identify the impact of building material waste due to design changes, hence reduce waste generation on construction site.

In IDP, engineers and other specialists translate the expressed values of the project, such as waste reduction, into systems that will achieve those aspirations. IDP allows engineers to work concurrently with architects as strategies emerge. This is especially important for environmental strategies, which often depend on efficient mechanical systems integrated into complementary envelope and structural designs. The feedback and collaboration from these members can identify clashes, design faults and deficiencies before construction starts, thus eliminating design mistakes which results in significantly lower waste. Specialists can provide added value by integrating their knowledge and perspectives to facilitate the right approach in achieving the team's goal during early design stage. If a green design specialist is involved in the design team, he/she may help identify potential green design strategies and direct team to green design resources in early design stage which helps potential waste to be reduced during construction stage.

It is also critical for the property/facility management team to be involved right at the start of the planning stage to give input into how the space will function on a daily basis. If the facility manager's involvement can be brought into the design phase, major repairs and alterations in the lifespan of the facility will be reduced [Mohammed and Hassanain, 2010]. They can provide feedback about how occupants might react to certain design features, or offer recommendations for optimising building operation and maintenance. Or even, plans could be made for how to reuse/recycle building material waste disposed from fitting out works, etc. Taking part in designing the building and ensuring that the building design enables efficient and simple maintenance will be highly beneficial to waste reduction when the building is completed.

Figure below illustrates the effort and impact relationship between traditional and IDP+BIM workflows across project phases.

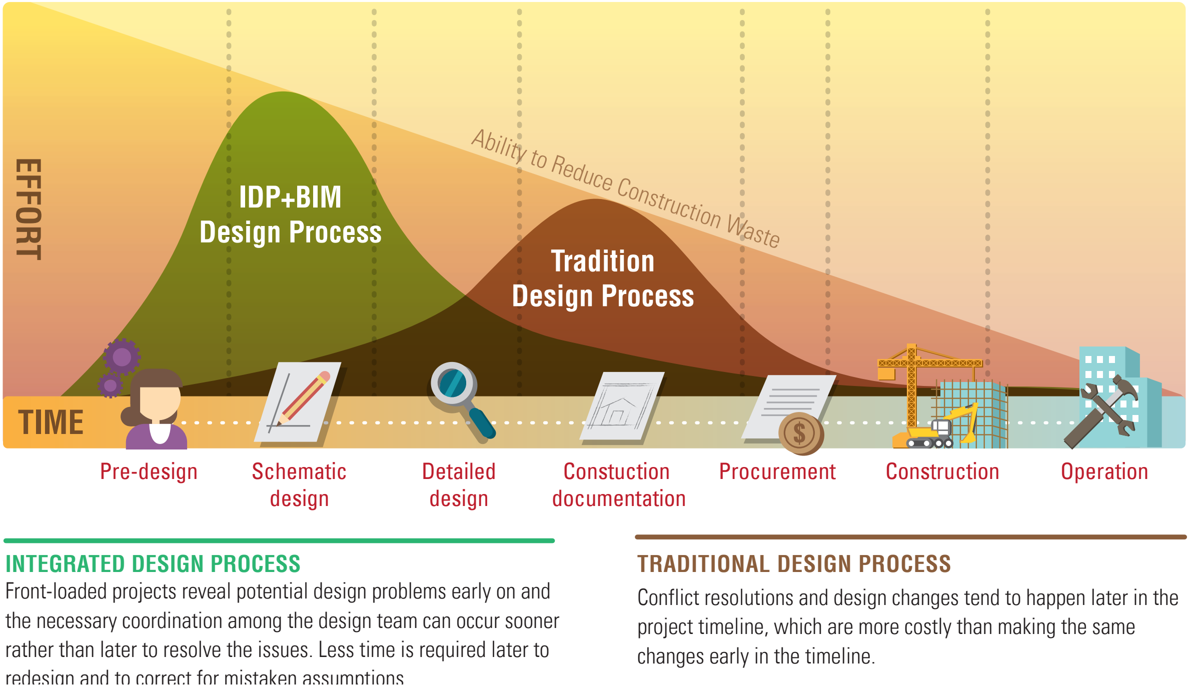


Figure 12 Comparison between a traditional and IDP+BIM workflow

In terms of project workflow, the ability to unify all aspects of the design and construction into a shared model is beneficial from numerous positions. Therefore, successful BIM implementation necessitates IDP, where most of the modelling time is consumed during schematic design and design development phases. Differ from traditional design workflows, most of the effort takes place during design development and construction documentation. The problem with this traditional workflow is that conflict resolution and design changes tend to happen later in the project timeline, which requires higher effort from the design team than making the same changes early in the timeline. One of the typical design faults includes clash of components where rework could be avoided if clashes are able to be detected at early stage.

In most IDP, the design time is distributed differently – more effort is spent upfront. But due to the better quality and completeness of decisions taken earlier, less time is required in later stage for redesign or rework to correct mistakes. As the problems have been solved early in the design and there will be fewer controversial faults in the plans and fewer design changes, especially by the engineers on the design team to redesign and correct mistaken assumptions. This reduces the impact on changes and thus less costly.

During construction documentation and administration (site visits, reports, and documentation), the workload is relatively low and levels off. The benefit of this is that front-loaded projects reveal potential design problems early on and the necessary coordination among the design team can occur sooner rather than later to resolve the issues. This can also avoid materials over ordering and material waste due to rework in construction stage.

As above figure shows, with the implementation of BIM, IDP shifts design and building project decision making to an earlier project phase when the ability to reduce waste is greater. For example, greater effort will be implied on the design team during early stage as all team members need to go through the learning curve together at the beginning of the project. The team and the project can therefore proceed much more quickly and efficiently and there is reduced risk of design faults and misunderstandings. When the common understanding of the project comes together in early design stage, issues such as redesign and resection work due to misunderstanding and design clashes will be less likely to arise, thus reducing risks of redesign, rework or material waste. Results from incorporating IDP and BIM into the project delivery ensure long-term success for all parties involved.

2.5 Case Study

One Taikoo Place

Over the past three decades, Taikoo Place has been transformed into a vibrant mixed-use development comprising office, retail, hotel and residential developments. One Taikoo Place, which will occupy the site of the recently demolished Somerset House, is being built using an integrated design approach, which positions sustainability at the centre of the design process and brings a multi-disciplinary design team together from an early project stage to collectively deliver sustainability solutions. This approach encourages innovation and the application of new technologies, and enables sustainability considerations to be taken into account during the design process. The integrated design approach not only includes members of the design team, but also members of the operation, management and maintenance teams, whose responsibilities span the life cycle of the building.

As such, One Taikoo Place was designed taking occupant and operational needs into account, with the design team using measured energy performance data of several buildings in Taikoo Place as an energy performance benchmark. This proactive approach has enabled Swire Properties to set ambitious sustainability goals, including energy-saving goals, beginning at the early planning stage.

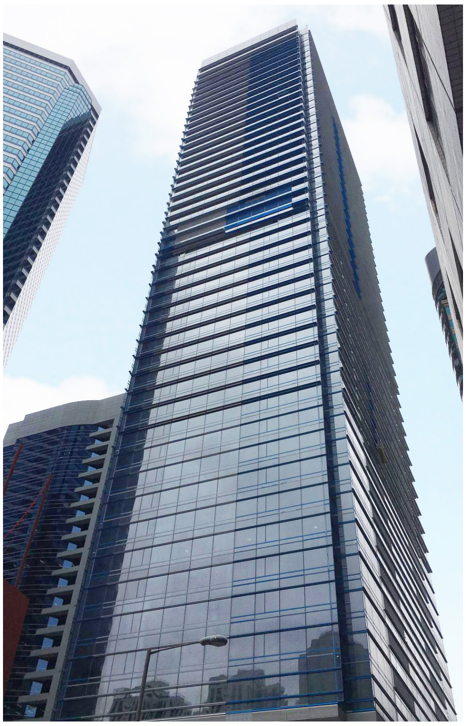


Figure 13 One Taikoo Place

A life cycle approach was also adopted in the development of One Taikoo Place. The demolition of Somerset House incorporated a sustainable waste management plan that followed the principles of waste avoidance (e.g. donations of fixtures and furniture to local charities for reuse), waste recovery (e.g. recycling of concrete) and waste disposal. During the demolition phase, more than 75 percent of demolition waste was reused or recycled.

CHAPTER 2 SUMMARY

TRADITIONAL DESIGN TOOL

- 1D-3D (design and build)
- Design changes resolve in later stage
- Limited collaboration and communication

TRADITIONAL DESIGN WORKFLOW

- Hierarchical structure
- More effort spent in later stage (more effort needed to correct mistake)
  Problems occur during construction
- Lower potential for waste reduction

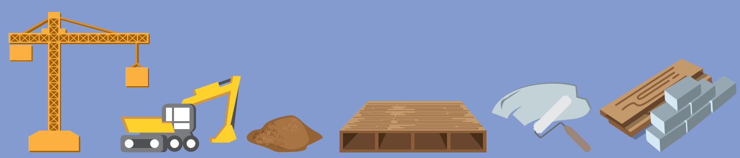
VS

BUILDING INFORMATION MODELLING (BIM)

- 1D-6D (entire life cycle)
- Clash detection at early stage
- Store data for entire life cycle
- Early collaboration among design team
- Work with Building Management System (BMS)

INTEGRATED DESIGN PROCESS (IDP)

- Involve clients, facility managers and multi-disciplinary specialist at early stage
- More effort spent upfront (to resolve problems)
- Higher potential for waste reduction



Chapter 3
Design for Construction

In general, *THE BUILDING CONSTRUCTION PROCESS CAN BE SUMMARISED INTO SIX MAIN STEPS, AND THESE STEPS ARE THE MAIN PROCESSES GENERATING BUILDING MATERIAL WASTE.* Figure 14 shows the typical building construction process. Preliminaries involve general site cleaning, removal of construction debris, as well as erection of site hoarding and scaffolding works. Earthworks mainly focus on excavation and backfilling. Formwork installations comprise the erection and stripping of formwork. Concrete works emphasise on in-situ casting of concrete. Wet-finishing works consist of brick/block laying, masonry, painting work, installation of sanitary wares and related plumbing works. Dry-finishing works involve carpentry and joinery work, glazing and other decorative works.

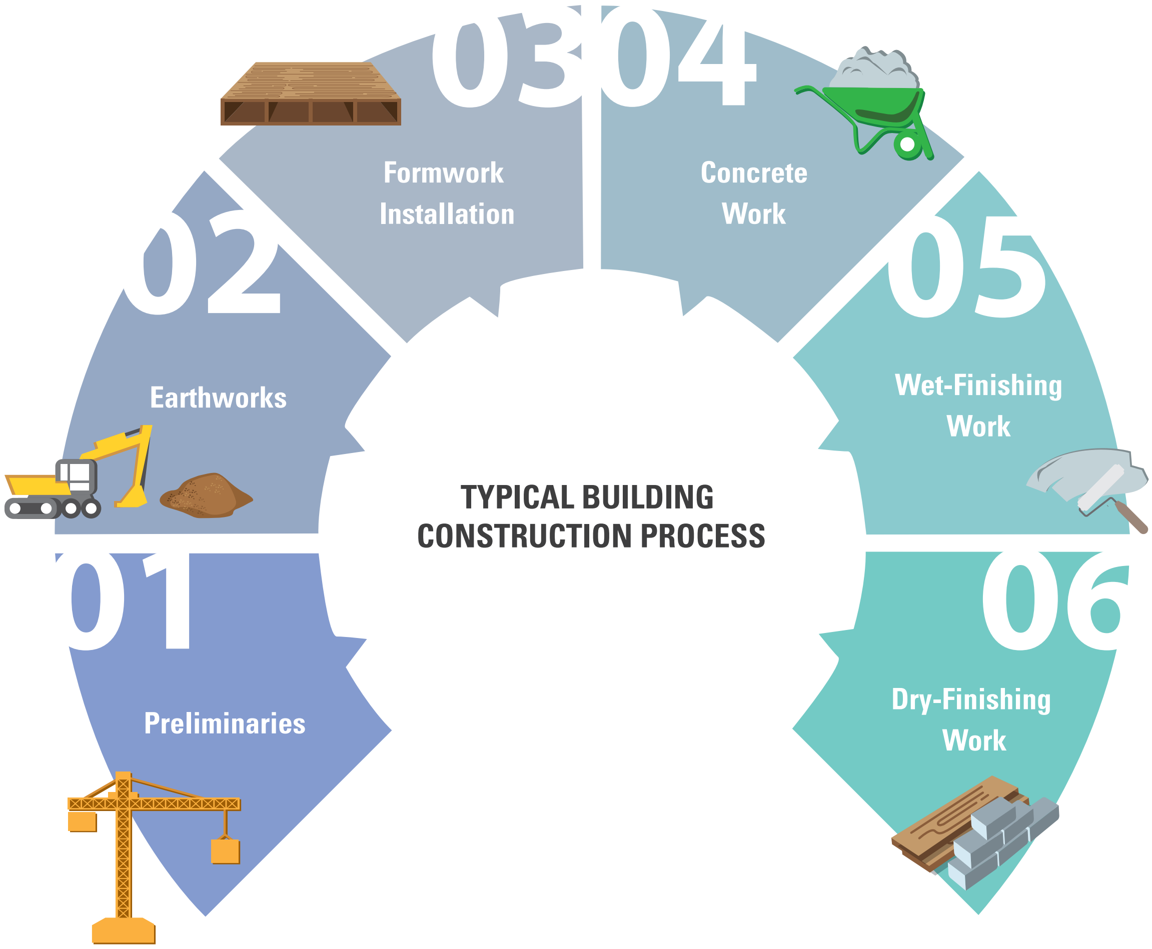


Figure 14 Typical building construction process

During the construction stage, the causes of building and electrical and mechanical (E&M) material wastage can be classified into two aspects, namely on-site work and installations, as well as materials handling.

The details of causes for these waste are listed as follows:

SITE WORK AND INSTALLATIONS	MATERIALS HANDLING
• Cutting waste • Poor coordination • Overproduction of in-process works • Errors in site fabrications • Poor workmanship • Defective work	• Unnecessary, excessive or incorrect materials Defective or scrap incoming materials • Inadequate protection of materials • Inappropriate site storage

Table 1 Possible causes for wastes in construction sites

A thorough design plan is conducive to enhancing the efficiency of construction and reducing building material waste. Followed by case studies and examples, several common construction methods and technologies are introduced in the followings chapters, including Prefabrication, Modular Design and Design for Manufacture and Assembly (DfMA).

3.1 Modular Design

Modular building designs and standardised room layout enhance precasting of building components such as façades, staircases, kitchen and semi-precast floor slabs. Off-site prefabrication can reduce cut-off wastage and the use of moulds on-site. Besides, factory controlled processes are more reliable, and can use more sophisticated techniques and fittings of which the net amount of materials employed can be reduced. Less waste is generated so dumping of material waste from site is much reduced to less than 30 percent of a conventional project (The Steel Construction Institute, 2000). Benefits of modular design are listed in Figure 15 and Figure 16 below.

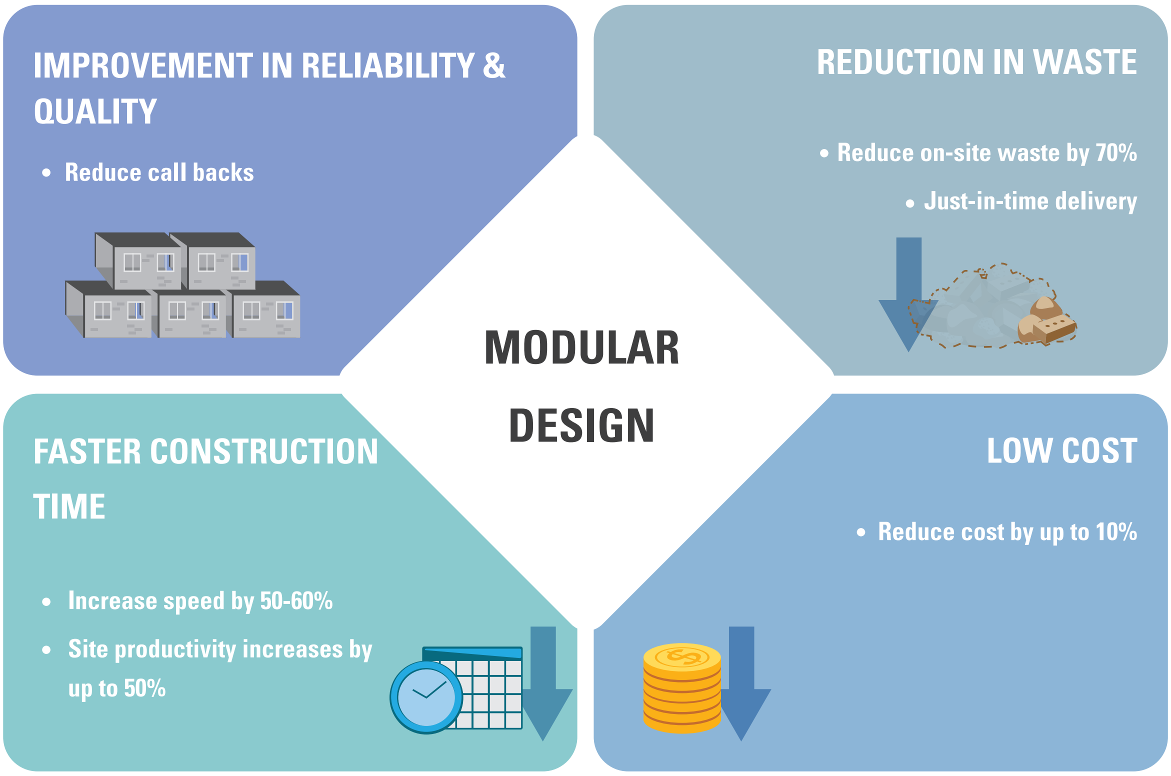


Figure 15 Benefits of modular design

Modular construction capitalises on the ability to produce the building components in controlled manufacturing conditions, and on tight control and project schedules. It is waste conscious with minimum site impact when building components have been delivered carefully and strategically with respect to site constraints. This is because modular builders work in a factory with controlled environment, they can have many building projects underway simultaneously in one location. Components or materials for a specific project could be re-inventory for use in another. With site built construction, overage will be sent to the landfill eventually. Waste is drastically reduced because of efficient factory production, and the reduced damage or use of packaging materials on-site. When modular units are prefabricated on-site, materials are used more efficiently, with considerable economy of use in production than is achievable on-site. Site installation of the modular units is a rapid and quiet operation that can be done just in time, as a result eliminates on-site damage of construction materials. Moreover, the delivery and installation of the modular units can be timed to observe any site working or road traffic constraints.

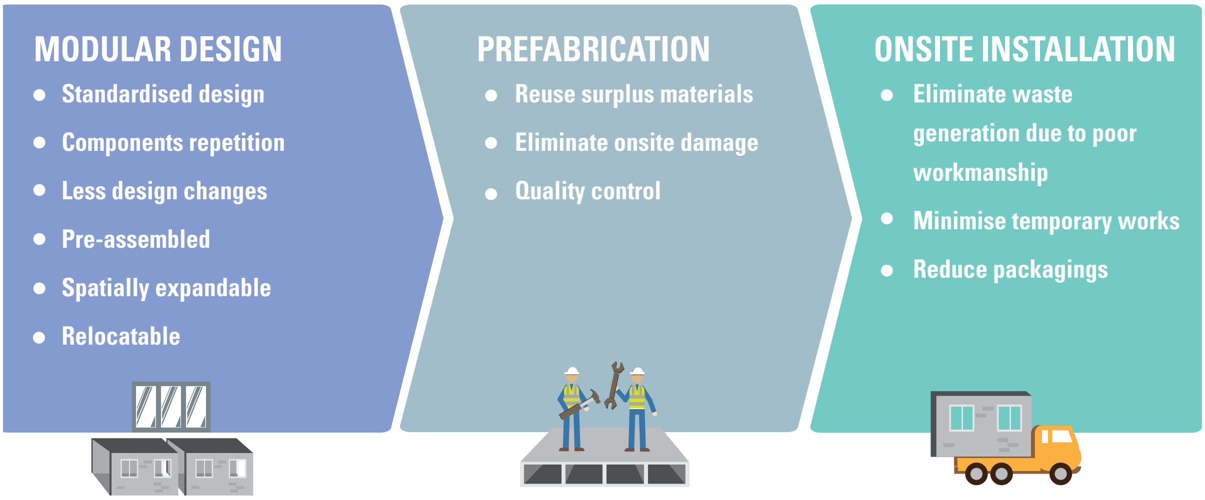


Figure 16 Benefits of modular design, prefabrication and on-site installation

In the past decades, HKHA has adopted a standard-block design approach in public housing developments. The design also adopts standardised dimensions, spatial configuration and components. HKHA has enhanced the technology in 2015. With further standardisation of shower design, use of volumetric precast components, wider application of mechanised construction technology and precast of parts and components, the quality, cost-effectiveness, construction efficiency and productivity have been further improved.

3.2 Prefabrication

What is Prefabrication?

Prefabrication is an off-site manufacturing process of assembling structure components at a specialised facility, and shipping the complete or partial assemblies to the construction site and casting in block as part of the final installation (Tam, Fung, Sing & Ogunlana, 2015).

Significance of Prefabrication on Building Material Waste Reduction

Prefabrication is a construction method that reduces the excessive use of materials. Not only it ensures on-site safety and productivity, but also greatly minimises building material waste and the pressure on landfills. Prefabrication is more sustainable than conventional construction methods. Figure 17 shows the differences between conventional and prefabrication construction methods [Mao, Shen, Q., Shen, L., & Tang, 2013].

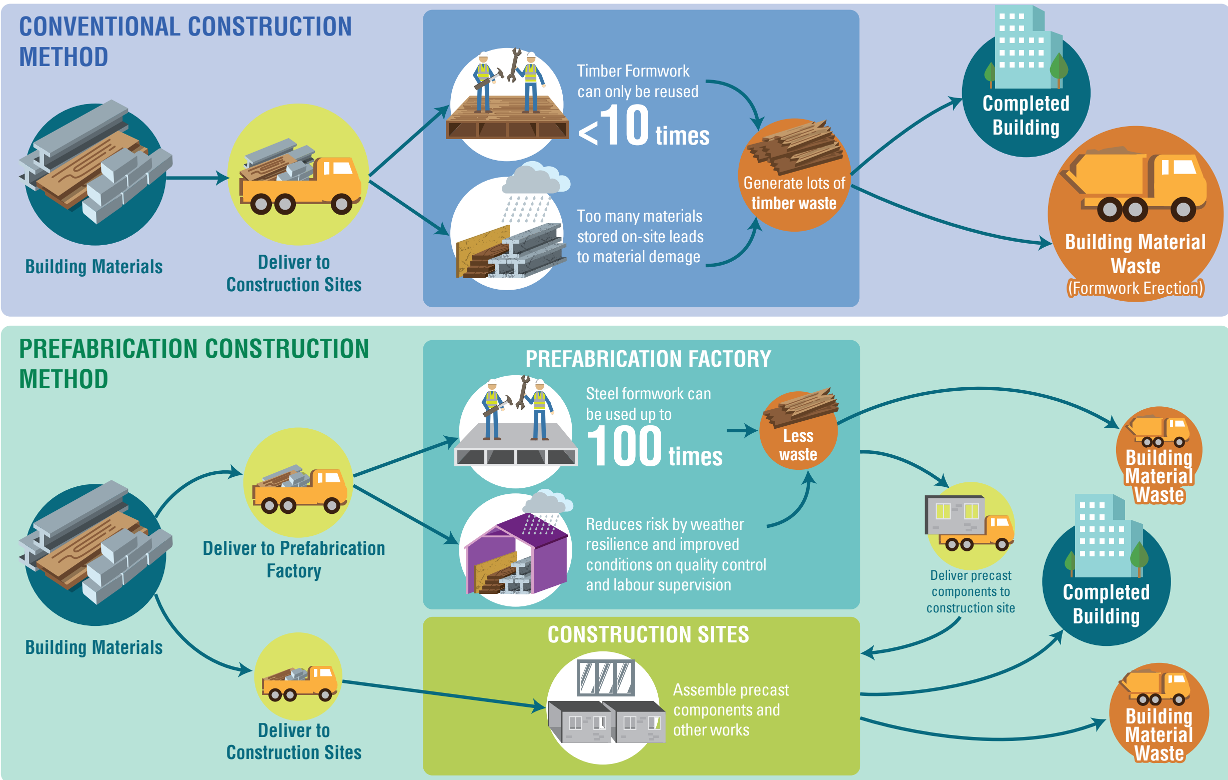


Figure 17 Comparison of conventional construction method and prefabrication construction method

One key difference between two construction methods is the use of formwork. In the prefabrication method, steel formwork is used. Compared to timber formwork which is used in the conventional construction method, steel formwork are stronger and more durable. They can be reused up to 100 or 200 times [Dong, Jaillon, Chu & Poon, 2015]. However, timber formwork can only be reused less than 10 times. As such, the use of steel formwork can significantly reduce the waste generation [Tam et al., 2015].

Apart from manufacturing process, reinforcing bar and concrete are apparently reduced by using prefabrication. This is because the prefabrication method provides more controlled conditions for weather, quality control and improved supervision of labour. As such, this results in reducing the requirement for on-site materials storage, and fewer losses or misplacement of materials [Li, Hong, Shen, Xu & Mok, 2016]. According to the case study of prefabrication carried out by Tam, V. W. Y. and Tam, C. M. (2006), waste emerging from timber formwork and concrete diminished by 74– 87 percent and 51–60 percent separately, these can definitely relieve the pressure on landfill [Jaillon, Poon & Chiang, 2009].

Use of Prefabrication

Around 65 percent of prefabrication projects in Hong Kong are residential buildings [Tam, V. W. Y., Tam, C. M. & Ng, 2007]. The use of prefabrication consists of three major activities, including concreting, plastering and formworking. Precast elements that are commonly used in prefabrication include façades, staircases, partition walls, parapet and slabs.

In order to further reduce waste in construction sites, it is recommended that more prefabricated components should be adopted, especially for private residential buildings. Prefabricated components, including precast beams, precast lift-cores, precast stair-cores, and precast lintels, have been adopted in public residential buildings. However, these precast components are uncommon in private residential buildings, meaning that there is a huge potential for those buildings to use these precast techniques.

Design for Manufacture and Assembly (DfMA) 3.3

Design for Manufacture and Assembly was originally divided into two categories: Design for Manufacture (DfM) and Design for Assembly (DfA).

DFM involves design which is easy for the manufacturing of products' constituent parts. While DFA is the method of design of the product for ease of assembly. However, DfA is only about reducing product assembly cost to minimise number of assembly operations. When it comes to similarities, both DfM and DfA aim to reduce labour cost, materials and overhead, along with product development cycle time.

To be more precise, choosing the most cost-effective materials and processes and minimising the complexity of the manufacturing process are two crucial parts of DfMA. Therefore, DfMA requires only necessary features with flexible components while cables, rubber and gaskets excluded – these materials are generally difficult to assemble. Also, components are designed for easy installation to further reduce time and effort.

By applying DfMA, a faster yet more controlled on-site installation could take place, leading to the fewer number of workers at construction sites – this could also reduce risk and improve safety for workers. Apart from this, using fewer components guarantees shorter assembly time. Last but not least, DfMA can greatly reduce the cost of assembly, including labour and material cost, along with lower cost of handling waste.

Prefabricated Prefinished Volumetric Construction (PPVC)

Prefabricated Prefinished Volumetric Construction (PPVC) is the new, advanced modular construction technology introduced by Singapore Building and Construction Authority (BCA) to promote construction industries towards higher productivity [Ong et al 2016].

According to BCA, PPVC is a construction method whereby free-standing volumetric modules, completed with finishes for walls, floors and ceilings, are constructed, manufactured and assembled in an accredited fabrication facility with any accredited fabrication method, and then installed in a building under building works. PPVC is suitable for commercial buildings, student residences etc. as these building structures usually have similar layout so that modules could be manufactured in bulk.

PPVC is one of the technologies that support DfMA to speed up construction as plenty of works done in an off-site yet controlled manufacturing environment. By doing so, manpower and time could greatly be reduced to save cost and enhance efficiency. Furthermore, reduced on-site works could lessen air and noise pollution, which is a significant benefit in a densely populated city. Little wet work is done on-site.

3.4 Case Study

Case Study of Public Housing by Hong Kong Housing Authority

The Hong Kong Housing Authority (HKHA) completed about 9,900 public rental apartments of six projects in 2014/15. HKHA has been using prefabricated components over the past 50 years. Figures below shows that precast facades, precast staircases, volumetric precast bathroom and semi-precast slabs are examples of frequently used precast components.

Figure 18 showcases typical precast components.

Figure 18 Examples of typical precast components used in the public residential buildings [HKHA, 2017]

Comparison of waste reduction

Case Study of Private Building - The Orchards

The Orchards adopted volumetric precast concrete elements including semi-precast balcony, sunshade, precast façade, lost form panel, lost form column and precast staircase. The precast components accounted for 50 percent in this project. It cuts down 56 percent of waste by reducing the use of scaffolding work and timber formwork [Jaillon and Poon, 2006]. In addition, the cost of prefabrication construction was only slightly more than conventional construction.

Figure 19 The Orchards adopted prefabrication which dramatically reduced more than half of the waste.

CONVENTIONAL CONSTRUCTION	PREFABRICATED CONSTRUCTION
HK$800/sq.ft	**HK$816/sq.ft** **Approximately 1% higher than conventional construction method**

Table 2 Cost comparison between conventional construction and prefabrication (Jaillon and Poon, 2006)

Comparison of cost and material use

Case Study of Private Building - Fu Tei

The 32-storey Fu Tei is the first residential building utilised precast structural elements in Hong Kong. Concrete prefabrication was adopted and extended the use of precasting to 50 percent. Nine standardised precast elements were used, including facades, semi-precast slabs, staircases, columns, balconies, shear walls, bay windows, kitchens and bathrooms. Prefabrication reduced cost from material use and manpower. It was found that over half of the material usage costs can be saved, and 30 percent of site manpower was largely reduced [Tam et al, 2015]. Moreover, the cost of external scaffolding was saved as it was not required for prefabrication. Environmental concern was satisfied and cost-effectiveness was significantly achieved. With 6 percent GFA exemption granted by Buildings Department, the use of prefabrication reduced 2 percent of the estimated cost comparing with conventional method [Tam, 2017].

Figure 20 Fu Tei project in Tuen Mun achieved the cost-effectiveness by utilising precast structural components

Case Study of Hong Kong and Shanghai Bank Headquarters

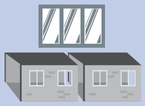
HSBC Main Building is the first building of its size in Hong Kong constructed entirely of structural steel without any reinforced concrete in its inner core. The building was designed by the British architect Lord Norman Foster and completed in 1985. High degree of prefabrication and modular design were adopted to foster the requirement to build in a short timescale. Apart from the advantage of short construction time, modular design predominantly minimised the waste generation since the precast components were produced in the factory. Moreover, it consists of five steel modules prefabricated in the UK and shipped to Hong Kong. One of the main features of the building is its absence of internal supporting structure. From the beginning of design stage, the building placed a high priority on flexibility and adaptability. Over a few decades, it has been able to reconfigure office layouts with ease. Waste generation has been minimised at the same time. All floorings are made from lightweight movable panels, allowing fast installation and easy maintenance of mechanical, electrical, and plumbing (MEP) systems.

Figure 21 HSBC Main Building

CHAPTER 3 SUMMARY

Design for Construction

MODULAR DESIGN

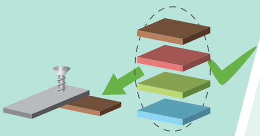


- Standardisation
- Components repetition
- Pre-assembled
- Spatially expandable
- Relocatable
- Less design changes

PREFABRICATION

- Reuse surplus materials
- Eliminate on-site damage
- Quality control
- Reduce packagings

DfMA



- Reduce labour cost
- Reduce materials and overhead
- Reduce product development cycle time

Chapter 4
Design for Operation & Maintenance

A WELL-PLANNED DESIGN LAYOUT NOT ONLY ENHANCES EFFICIENCY DURING DEMOLITION AND CONSTRUCTION, IT ALSO HELPS A LOT WHEN IT COMES TO FUTURE MANAGEMENT AND MAINTENANCE.

Considering future management and effective ongoing maintenance at the design stage can save resources and reduce waste in the long-term. Arditi and Nawakorawi (1999) stated that 50 percent of the maintenance related problems can be eliminated if design defects can be prevented during the design phase. It is crucial for building designers to consider how materials can be maintained and refurbished effectively during building life cycle.

In order to reduce avoidable waste generated during the operating stage of a building's life cycle, it is extremely important to consider for future management and maintenance when designing a building.

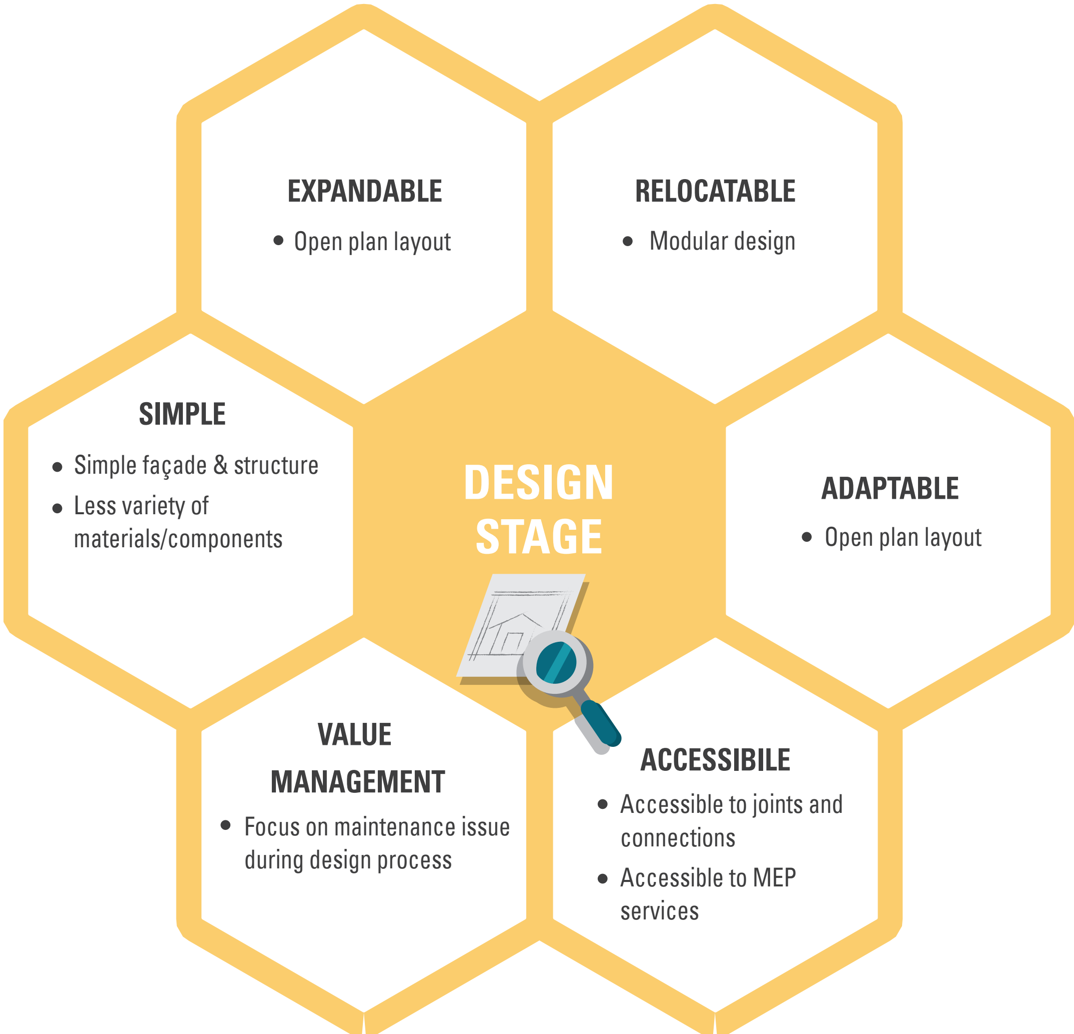


Figure 22 Design considerations for future management and maintenance

To accommodate future changes of a building, such as rearrangement of spaces, the building layout shall be designed to be expandable, adaptable and relocatable. Simple façade and structural design also allows future maintenance to be carried out more easily, therefore reducing the chance of the removal for the whole component. Joints, connections as well as MEP services shall be designated at an accessible area for regular checking and easy maintenance. Therefore as mentioned in Chapter 2, facility managers shall be involved at the design stage to offer advices on maintenance issues.

4.1 Design for Adaptability

As architectural techniques advance, the lifespan of buildings extends and future expansion is getting more common. Change of use and future expansion require modifications to the building layout. Such modifications could produce plenty of waste including walls and partitions. A flexible layout can greatly reduce resources consumption and generation of building material waste. Design for potential amendments to the layout is necessary in order to minimise waste. In other words, design for adaptability before construction should be considered.

Study [Pinder, et al., 2017] defines adaptability as – a design characteristic embodies spatial, structural, and service strategies which allow the physical artefact a level of malleability in response to changing operational parameters over time – it refers to the capacity of buildings to accommodate substantial changes.

The concept of Design for Adaptability (Figure 23) can be broken down into 3 simple strategies: flexibility, convertibility and expandability.

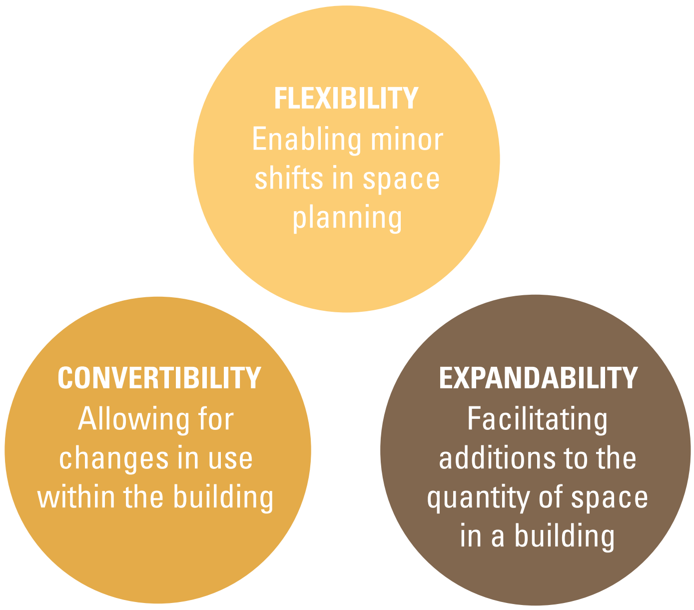


Figure 23 Concept for Design for Adaptability

Adaptable buildings are likely to be flexible and with space planned more efficiently for the need for changes or expansions. Convertibility of a building allows spaces to be used for other purposes as new needs arise. Expandability allows the building to accommodate much higher densities with the same footprint and infrastructure. Design for adaptability can also increase the longevity of buildings and improve operating performance. A study from International Energy Agency (IEA) indicates that if a building has features that allow easier adoption of new, efficient technology, it is reasonable to assume an increase in average lifetime operating efficiency of 10 percent or more.

The key design principles include independence of systems within a building, upgradeability of systems and components, and lifetime compatibility of building components. A number of design considerations have been summarised for each element of a building in Figure 24.

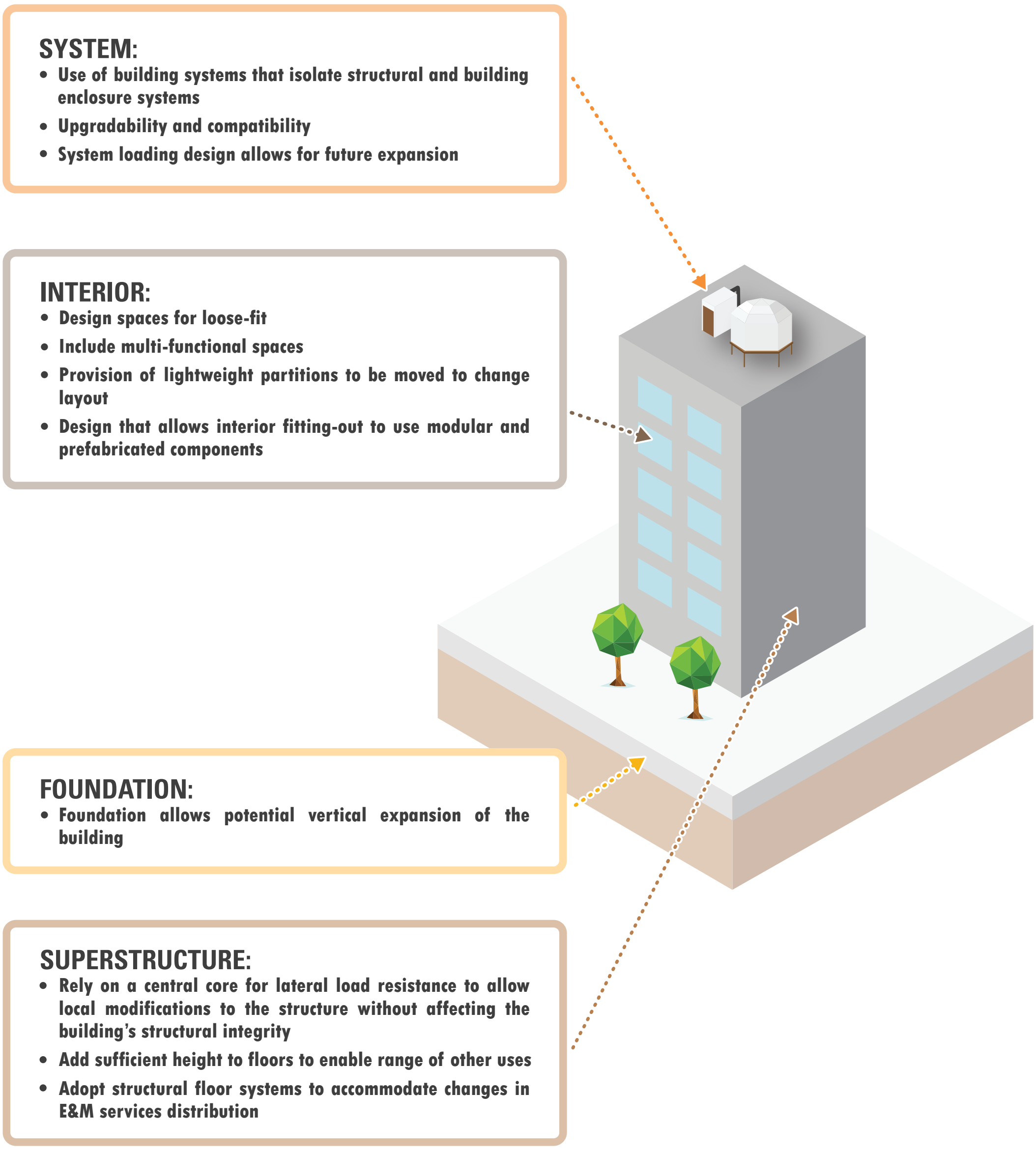


Figure 24 Design considerations for adaptability

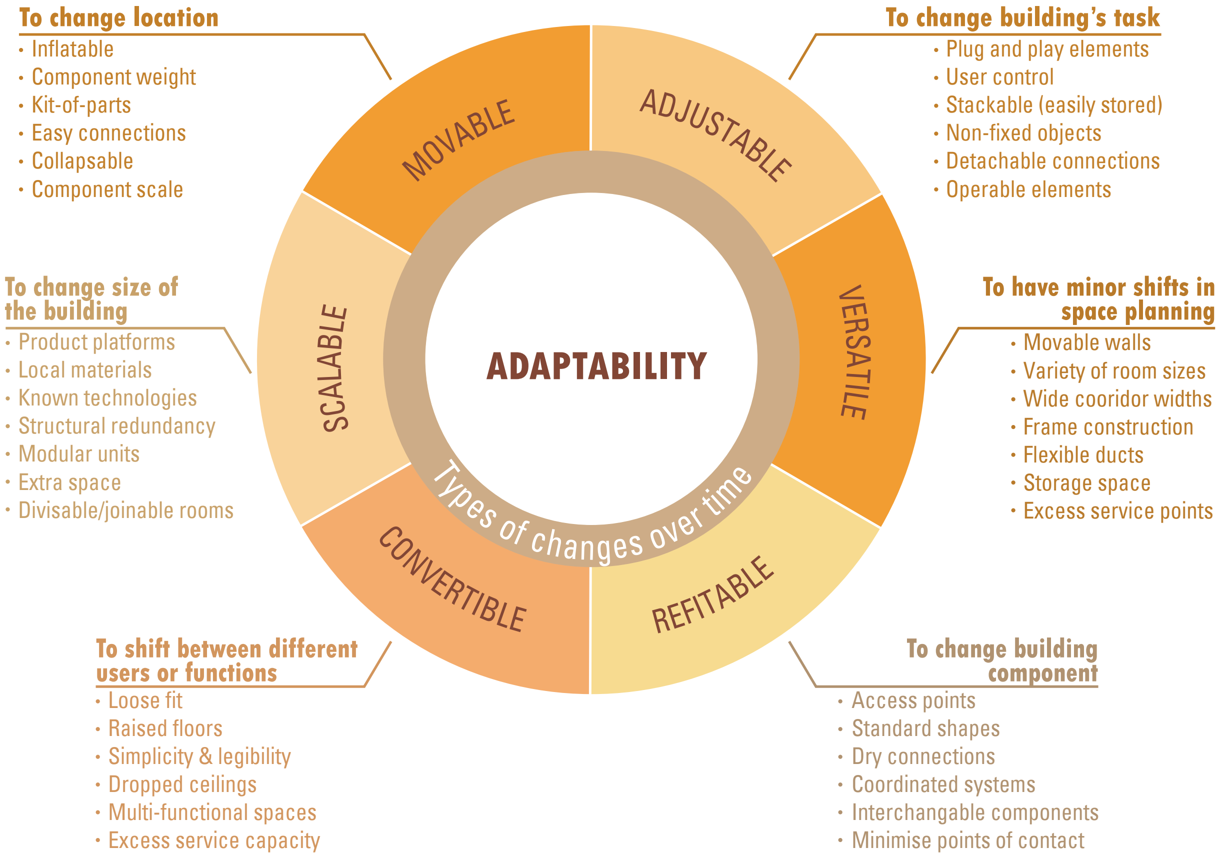


Figure 25 Design principles for adaptability

A building that is designed for adaptability with the right mix of flexibility and durability would be designed [Dave, Varshney & Graham, 2012]:

- with the end of the building life in mind
- considering it as a system of temporal layers and accommodating the changes the building and its components would undergo during the entire life cycle
- for long life: or for long-term durability and sustainability of the building and durable amenity for its occupants
- for loose-fit: or for spatial and structural flexibility to assist materials and components change or deconstruction: or for independence between different layers or components with different functions to aid in disassembling for reuse, recycling or replacement

The Theory of Open Building

The design of traditional buildings is based on functionality while spaces are designed to have only one function. However, open building design concept is about:

people and time and architecture, space and function start to have a different flexibility from the previous at different levels as people have the "interaction" with time and need, start with little tricks, save resources and costs while meeting their new needs, so as to better ensure the use of the building's life cycle [Ni, Chen, X., Chen, W., Gan, Z. & Zhang, C., 2017].

FEATURE	PRINCIPLE
Hierarchy	• The interior of the building should be divided into different levels, each level is relatively independent and has different timelines
Participatory	• Enhance the interaction between people and architecture by involving professionals and end-users
Relevance	• Various systems in the building correlate to each other for convenience of rethinking and piecing
Flexibility	• Allow disassembly and modification

Table 3 Features of open building

Guidelines to Integrate Adaptability in Building

After knowing the key concepts and principles of design for adaptability, the question of how to apply would be the most difficult part. These guidelines consist of six areas: socio-professional, economical, spatial and functional, structural, technical and façade. Some of them have already been briefly mentioned in Figure 24 and Figure 25:

Socio-professional

Socio-professional guidelines encourage flexible thinking. The professionals are advised to promote open building theory and keep spending effort in the transformation and evolution process rather than pursuing a perfect finished product.

IDP is crucial to socio-professional guidelines. Different decision making levels in the design, construction and modification of the building have to be involved and their responsibilities have to be clearly stated. End users' participation are necessary but their intervention should not override formal control. Also, this field encourages professional interdisciplinary and coordination between the different specialists (urban designers, architects, interior designers, engineers, etc). Precise and differentiate the responsibilities in order to reduce dependency, conflicts and interferences.

Economical

Economical guidelines propose simple yet inexpensive solutions and invest more in the design construction rather than modifications and maintenance.

Spatial and functional

Spatial and functional guidelines propose that the design of building is a combination of independent system-based layers organised hierarchically according to their expected lifespan and rate of change, including structure, circulation routes and access, envelope, technical services and installations, space plan and furniture. Such design could minimise the use of beams and columns.

To minimise future modifications, layouts should include multi-functional spaces and buffer zones allowing for a large variety of functions, as well as trans-functional spaces. Partitions and furniture that are light, mobile, demountable, reusable and recyclable are advised to include to increase mobility.

On the other hand, designers could also enhance the space density by multiplying the activities places without expanding its topological dimension (e.g. Menger sponge) to take advantage of every millimetre of the space in height and area. Modularity is another way to facilitate reconfiguration, subdivision and easy rearrangement of spaces.

Structural

The foundation of building could be designed for future expansion and extra loads. For superstructure, minimising the number of internal columns and bearing walls, along with using a wide structural grid and generous floor-to-floor height are conducive to future changes. Designers could also make the support structure divisible, enabling future independence of compartments.

Technical

Embedded ducts and pipes with easy access in other building systems, such as walls and floors, could prevent future rearrangement from taking place. Pluggable connections and wireless systems are preferred as they are inexpensive and easier to reduce problems of connections, cables and ducts.

Prefabricated and standardised components, along with modular coordination, are easier for replacement and recyclability.

Façade

The building envelop should be independent of the structure and provide means for access (to the envelop system) from both inside and outside the building to facilitate maintenance and repair. The façade design could be based on modular design to allow replacement, updating, integration of new technological features and suit of fashion.

Building Management System (BMS) 4.2

What is Building Management System (BMS)?

Building Management System (BMS) is known as microprocessor-based controller networks installed to monitor and control building technical systems and services such as air-conditioning, ventilation, lighting and plumbing. More specifically they link the functionality of individual pieces of building equipment so that they operate as one complete integrated system.

The introduction of BMS provides savings by ensuring that the plant is operating at its peak efficiency whenever it is used and that it only operates when needed. Studies have shown that, with careful management of the system, energy savings of 10-20 percent can be achieved while maintaining, or even improving, comfort conditions.

A BMS provides the opportunity to closer control over the plant and to use the most adequate procedures to ensure optimum performance of a building. On the other hand, time and costs could be reduced during maintenance since the BMS is able to detect and identify potential problems of the building services systems. This also improves plant reliability and durability, hence reducing waste. Apart from controlling building services systems and monitoring indoor environmental quality (IEQ), BMS also collects data being evaluated and transferred across the systems and produces details for trend analysis, building performance and maintenance scheduling. This provides an ideal opportunity for determining energy consumption, operating hours, room temperatures, etc.

With the development of BIM, knowledge sharing between facility management and design professionals becomes possible. BIM models can be very useful during post-construction if they have been created with that use in mind. A BIM programme being designed specifically for building operators can automate the creation of equipment inventory lists, occupy facility management systems, and reduce redundancy in the maintenance data. This allows facility managers to focus on preventive maintenance and optimising systems instead of repairing. Building owners need to plan and communicate to the design team how the facility managers might use the BIM models to improve operation and maintenance once the building is completed. Some of these uses might include transferring the as-built data into the facility management system, running ongoing analysis of operational capabilities, or using the models to support future renovations. This would require specifying requirements for interoperability and an as-built model up front.

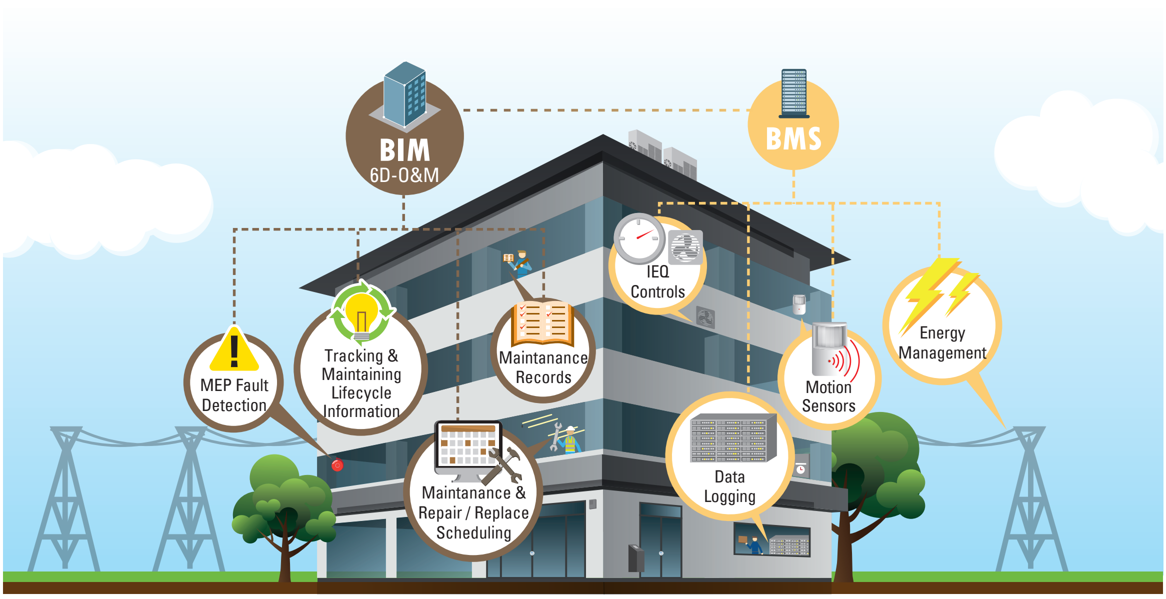


Figure 26 Use of BMS and BIM during operation stage

Case Study on BEAM Society Limited (BSL) – Office RenoGreen

BSL is the founder and owner of the Building Environmental Assessment Method (BEAM). The office of BSL has achieved the Platinum Rating under BEAM Plus for Interiors (BI) v1.0 Accreditation upon the renovation of the existing office itself.

The office floor adopted over 75 percent of reused carpet tile. Besides, more than 60 percent of furniture including partitions, desks, chairs and cabinets are reused from salvaged organisation. File cabinets, drawers, pantry cabinets, wall shelves were made of solid wood floorboards which were recycled from materials removed or disposed from other renovation sites.

Figure 27 Cabinets transformed from solid wood floorboards in Office RenoGreen

Case Study on Architectural Services Department – Renovation of 1/F Main Block APB Centre

Located in Hung Hom, the new Architectural Services Department (ArchSD) office is the first Government office in Hong Kong achieved Platinum Rating of BEAM Plus for Interiors (BI) Accreditation.

Designers of the building tried utmost effort to minimise the consumption of natural resources. More than 50 percent of the newly installed materials were from sustainable sources. For example, the new office used bamboo for wall covering and skirting, a renewable material with a harvest cycle less than 10 years. Doors were made of sustainable timber as well. Last but not least, sustainable materials were applied to the raised floor system and carpet.

Figure 28 Green wall along the main corridor of APB Centre

Most of the factories of the materials used in this project were environmentally friendly factories certified under ISO 14001. They are located within the distance of 800km from Hong Kong to reduce carbon emission of transportation.

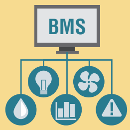
CHAPTER 4 SUMMARY

Design for Operation and Maintenance

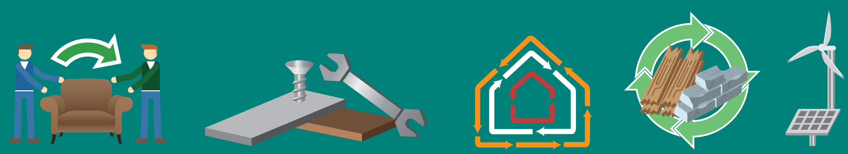
DESIGN FOR ADAPTABILITY

- Adjustable
- Versatile
- Refitable
- Convertible
- Scalable
- Movable

BUILDING MANAGEMENT SYSTEM (BMS)



- Link the building equipment as one complete integrated system
- Collect data being transferred across the systems and produce details for trend analysis, building performance evaluation and maintenance scheduling
- Ensure optimum performance of a building
- Integrate with BIM models to support regular maintenance and future renovations
- Transfer the as-built data into the facility management system, running ongoing analysis of operational capabilities



Chapter 5
Design for Demolition

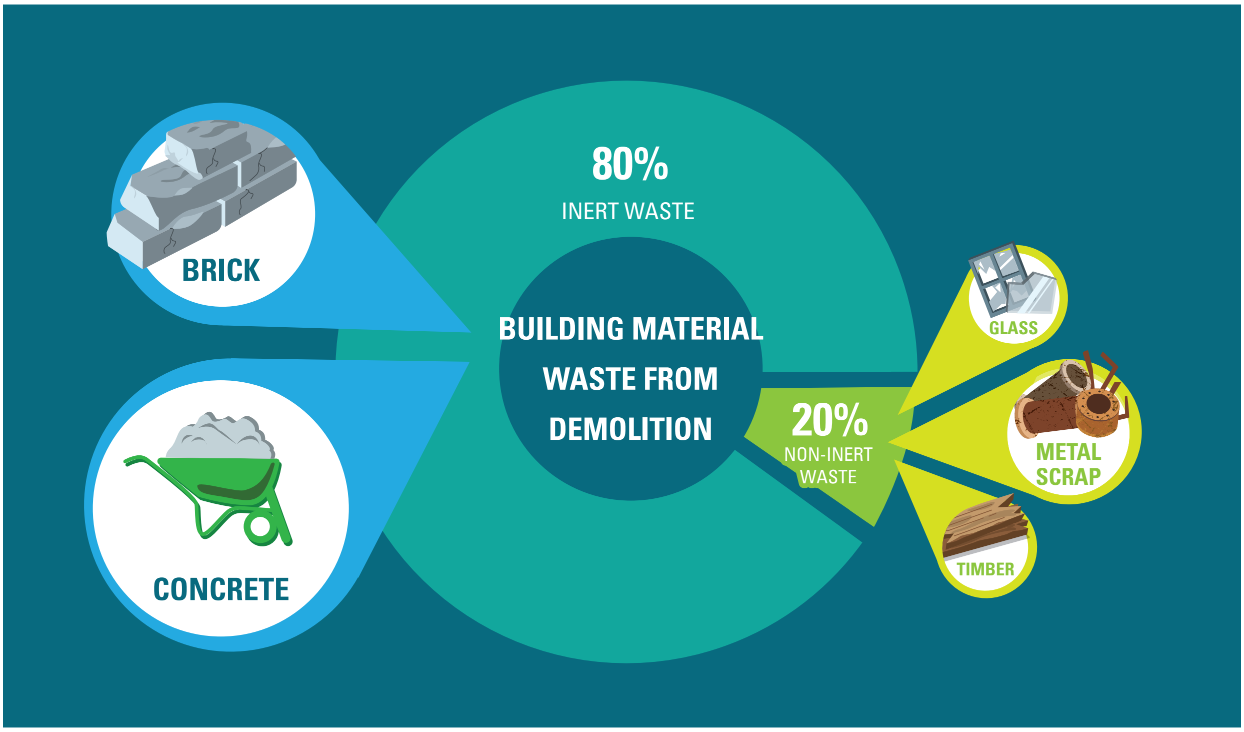


Figure 29 Major categories of building material waste from demolition in Hong Kong

In most cases, the dismantled materials generated are comprised of inert and non-inert waste when the whole building is demolished (including substructure and superstructure) where *INERT WASTE OCCUPIES ALMOST **80 PERCENT** OF TOTAL BUILDING MATERIAL WASTE FROM DEMOLITION.* It mainly comprises of sand, bricks and concrete, which are inactive with most of the chemical agent and non-biodegradable by natural environment. The remaining portion of building material waste is classified as non-inert waste, including combustible materials, glass, metal scrap, timber and different types of plastics as shown in Figure 29. All these non-inert waste can be divided into three groups based on its characteristics that are vendible, reusable and non-reusable. Reusable non-inert material can be directly reused after certain treatment process, and non-reusable waste cannot be sold or reused with or without treatment.

BEAM PLUS FOR NEW BUILDINGS VERSION 1.2 ALSO ADDRESSES THE CONCERN ON BUILDING MATERIAL WASTE DISPOSED DURING DEMOLITION as shown in Figure 30. *IN MATERIALS ASPECT (MA 10), CREDITS ARE GIVEN FOR BEST PRACTICES IN THE WASTE MANAGEMENT, INCLUDING SORTING, RECYCLING AND DISPOSAL OF DEMOLITION WASTE.*

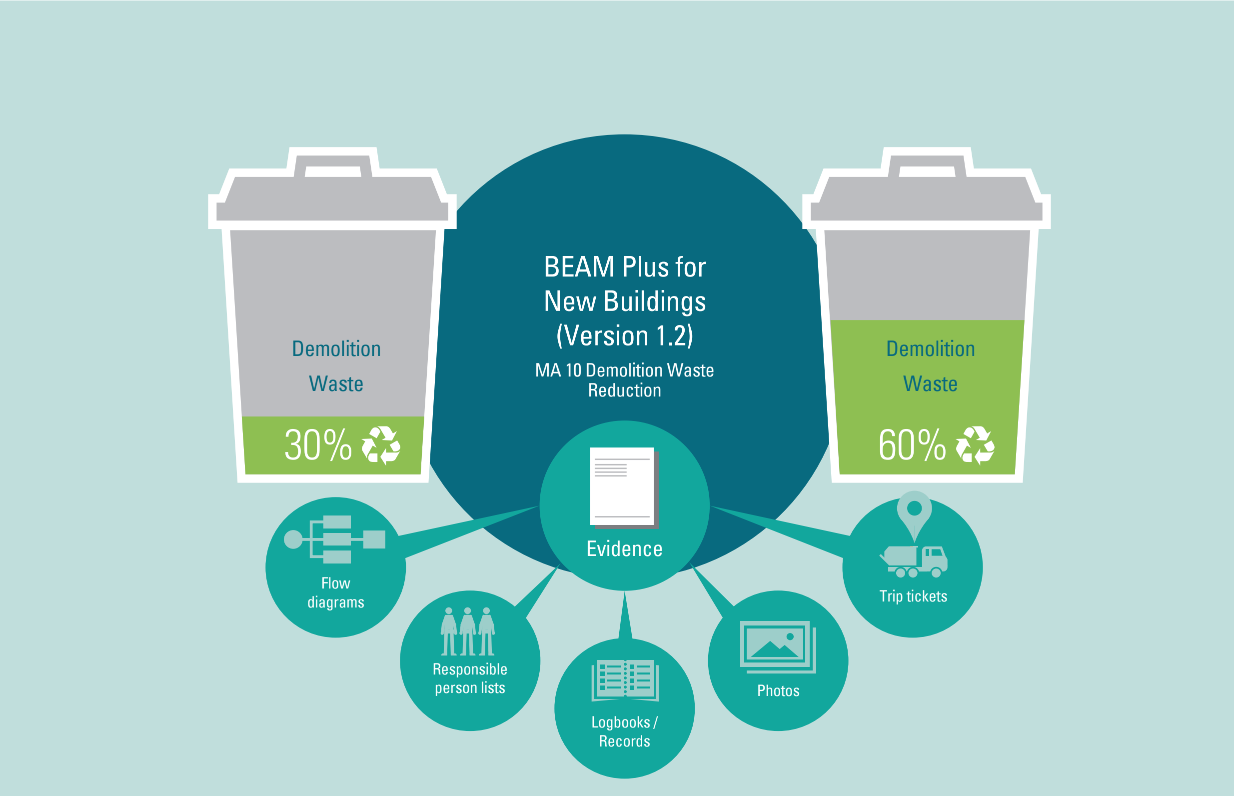


Figure 30 Details of BEAM Plus for New Buildings in demolition waste reduction

5.1 Design for Disassembly (DfD)

Reusing and recycling building material wastes are great approaches to achieve sustainability. However, there are difficulties to reuse and recycle building material wastes without good planning before demolition. To facilitate the process of extracting materials of a demolished building, practitioners are advised to plan with the idea of "Design for Disassembly (DfD)" in early design stage.

By designing buildings with the concept of DfD, it can tighten the loop of materials use in buildings, minimise the use of virgin materials and relief the burden of landfills (as illustrated in Figure 31). DfD also allows maximum flexibility of spatial configuration within a given structure, as this preserves the building structure as a whole. DfD requires rigorous planning and execution at every stage of the design process. If not, the effect of future reuse and recycling will be greatly hampered.

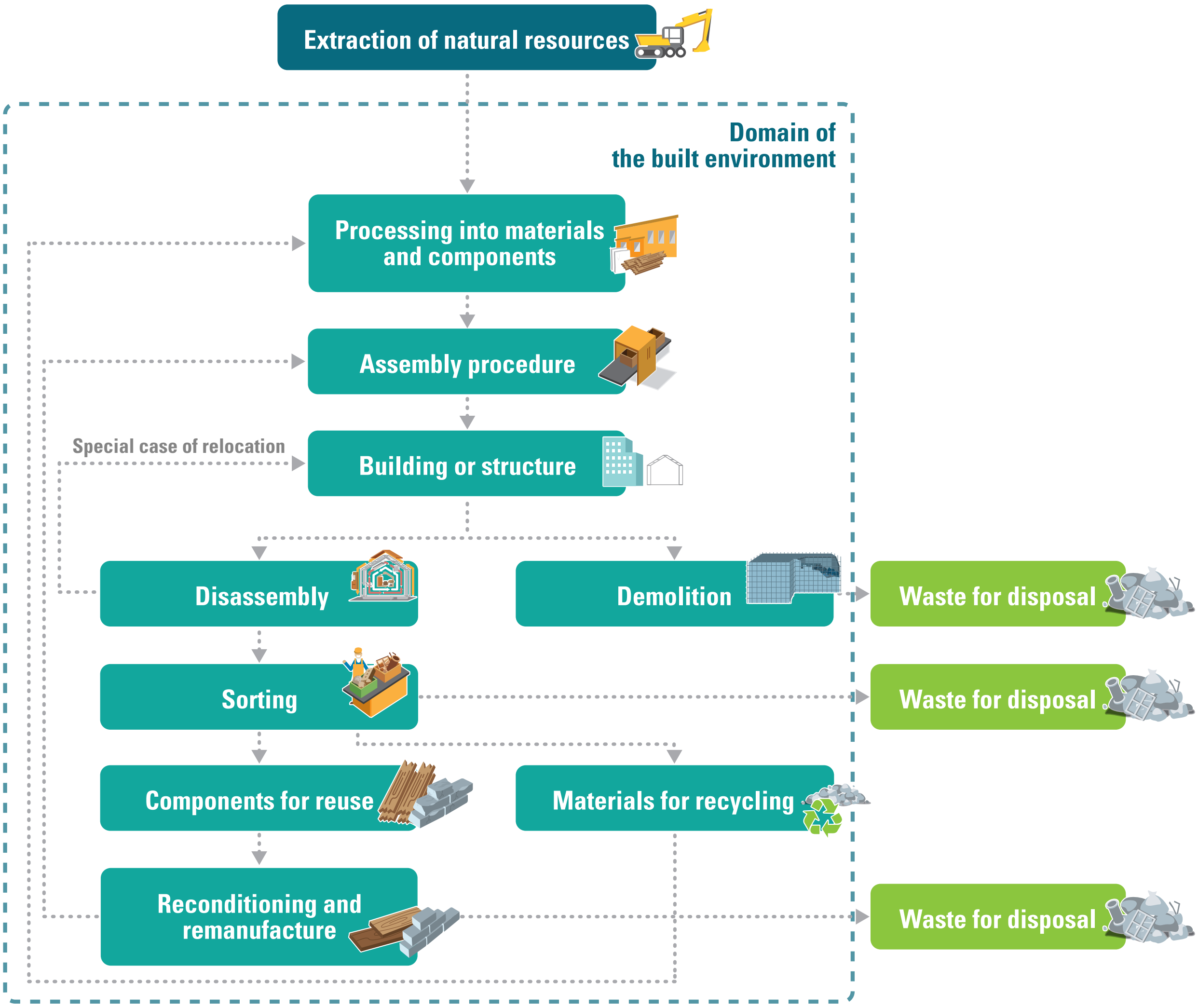


Figure 31 Flow chart of a building's life cycle with DfD in mind

The principle of DfD refers to the design of buildings which facilitates future changes and demolition (in part or as a whole) for the reuse of systems, components and materials. This design process includes developing the assemblies, components, materials, construction techniques, and information and management systems to minimise waste. DfD enables flexibility, convertibility, and addition and subtraction of a building. Therefore, it could help avoid the removal of the entire building and its systems altogether.

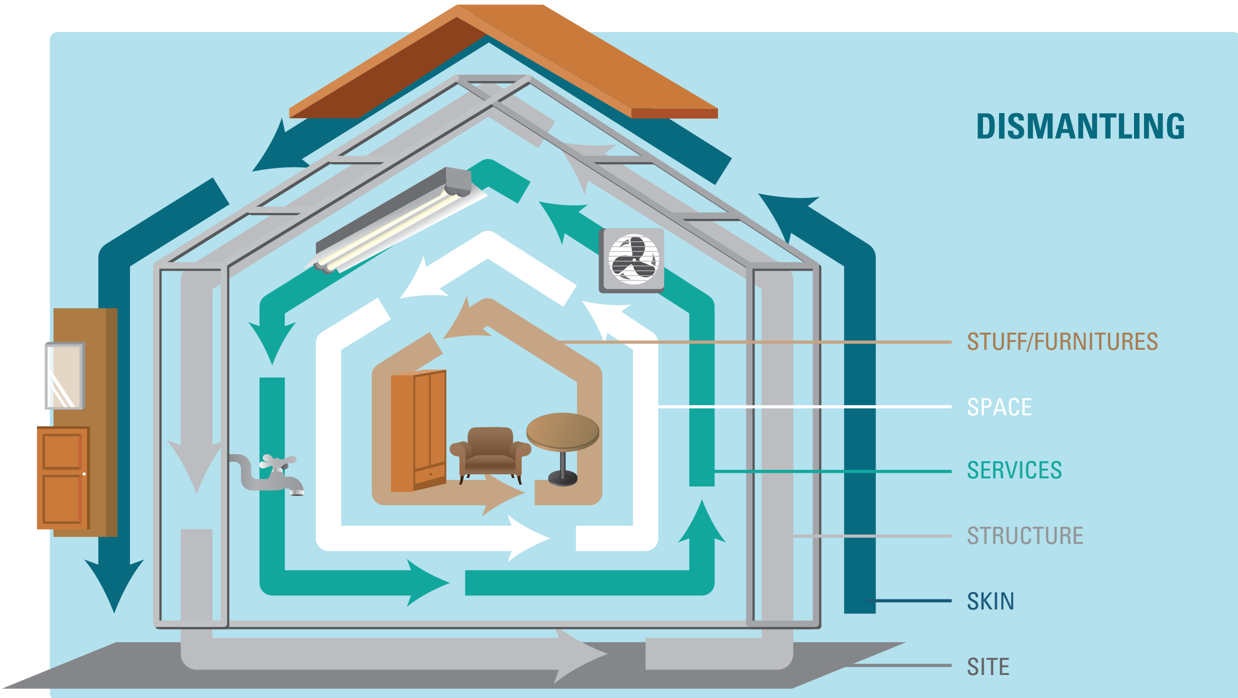


Figure 32 Different layers of a building

According to Steward Brand's 6S theory, a well-designed building consists of separate layers and each of them has different lifespans. For example, the building structure may last for more than a few decades, whereas the cladding only lasts about 2 decades. Thus at the cladding's end-of-life, the structure is still functional. The cladding of a building designed with DfD should be easily separated from the structure and at the same time, preserves the entirety of the building. The services layer contains the building's MEP systems and needs to be replaced every one or two decades [Li, 2015]. If the services layer is poorly attached to the structure, which makes it difficult to be detached and replaced, the lifespan of the entire building will be shortened while also wasting materials. In terms of how to facilitate DfD in a building project, a few considerations are shown in Figure 33 and elaborated below.

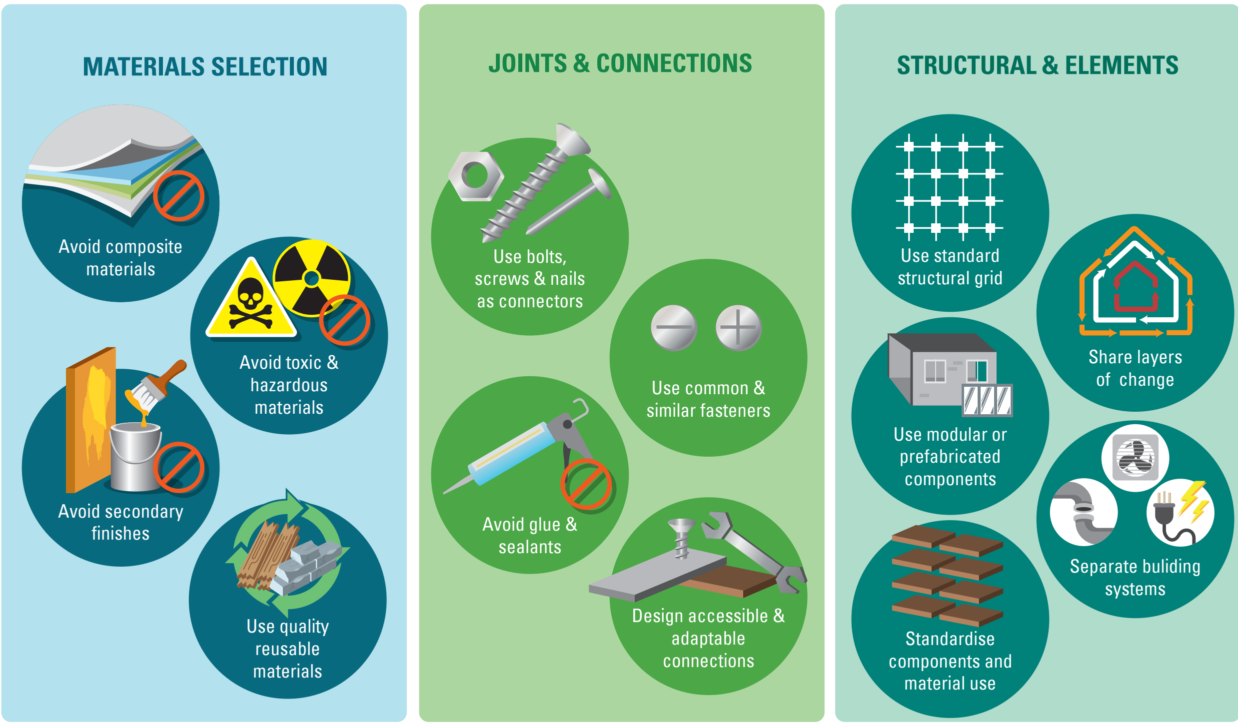


Figure 33 Key considerations of DfD

Current barriers in disassembling building or structure include the prevalence of materials that become environmental hazards and the difficulty to segregate materials without damaging for reuse or recycle. Therefore during design stage, it is important to consider components that are durable enough to be repaired or reused with minimum work and cost as well as to be readily recovered without damage. Components should be designed to maximise the number of times they can be reused. If a component or system is unlikely to be reused, it should be easily broken down into individual materials for recycling.

For MEP systems, problems such as entanglement of HVAC, electrical and plumbing systems within walls, floors and ceilings, etc. have become a major challenge of recycling MEP systems during demolition. Therefore during design stage, separating building systems is required to allow more flexibility and changeability which environmental impact of materials used is adequately addressed. When one system is removed, other systems should remain intact to have a longer useful lifetime.

In terms of disposal of building material wastes, DfD includes the use of quality reusable materials, such as materials intended as recycling feedstock and materials which are easily dismantled. Use of composite materials and inseparable products should be prevented so that they are easier to be recycled. Toxic and hazardous materials should be avoided as it might increase potential health impacts and technical difficulties. Secondary finishes to materials should also be avoid if possible as this may cover connections and materials, hence making it more difficult to find the connection points while dismantling [Guy and Ciarimboli, 2005].

A simple structural design guarantees an easy disassembling process. For example, using a standardised structural grid would allow for standard sizes of recoverable materials. As mentioned above, structural elements should be separated from non-structural elements to allow for future non-structural demolition. On the other hand, modular design and prefabrication can also promote DfD at a larger scale. Modules and components should be standardised for reuse thus making both deconstruction and construction easier. Moreover, building layout should provide adequate tolerances to allow for disassembly in order to minimise the need for destructive methods that will impact adjacent components.

Bearing DfD in mind, joints and connections should be designed as simple as possible. As standard and palettes of joints and connectors would decrease tool needs, time and effort to switch between them. Designers should prevent the use of inaccessible connections which can cause damage in the process of separating materials. On the other hand, visually, physically, and ergonomically accessible connections would increase efficiency and safety protections for workers.

5.2 Demolition Planning

Figure 34 shows the comparison of varies demolition methods. The selection of demolition method depends on resources availability, project scale and contract requirements. The chosen demolition method would affect the sorting efficiency and regularity of the material size during demolition.

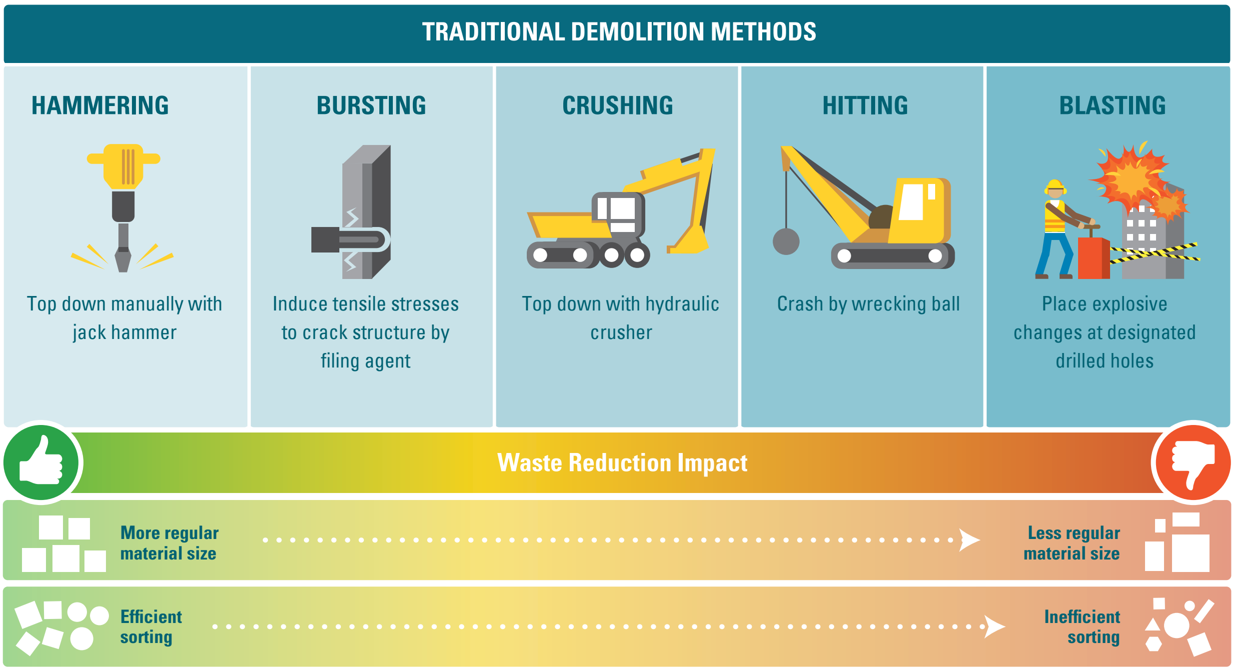


Figure 34 Comparison of waste reduction impact against different demolition methods

Knowing the Hong Kong's situation in handling materials generated from demolition projects, there are some suggestions for the industry.

Selective Demolition

One of the suggestions is to carry out selective demolition planning. The Buildings Department issued the "Code of Practices for Demolition of Buildings" in 2004. The Code introduces the concept of sequential demolition in order to facilitate better material recovery.

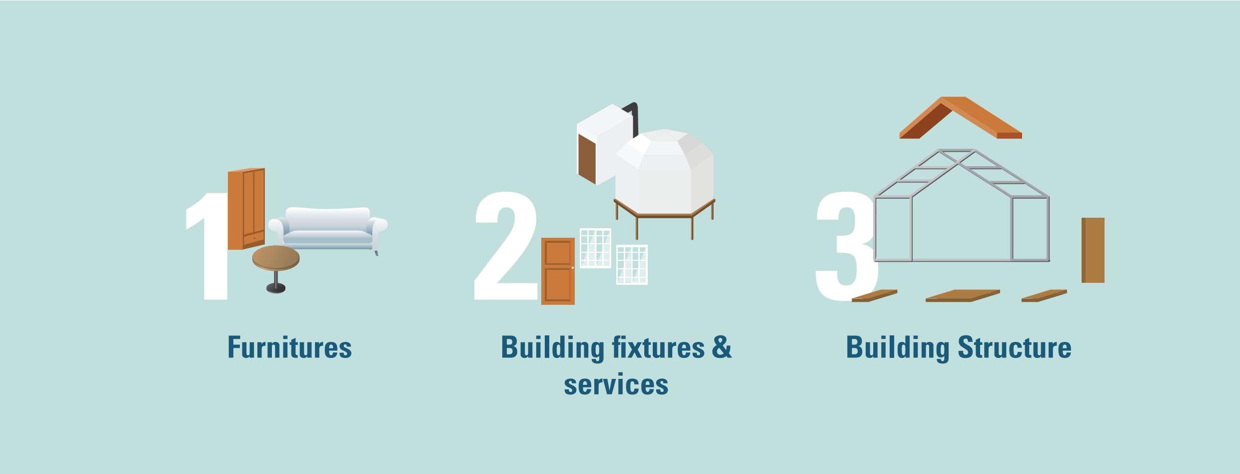


Figure 35 Planning procedures of selective demolition

Figure 35 shows the proposed sequence of selective demolition. It starts from removing the furniture and non-fixed items. After cleaning up the interior spaces, fixed equipment including building services materials and installed items on the structure, such as doors, windows and carpets, would be dismantled. Lastly, all bricks, walls, steel and concrete structure would be demolished.

Different types of materials are separated in various stages of the selective demolition process. Dismantled materials are removed without spending extra labour for cleaning and sorting. Better sorting could also facilitate the collection of materials by recycling companies.

Selective demolition planning guarantees efficient sorting because demolition is conducted in a by-layer and by-category manner. For furniture and fixed equipment, similar types of materials are put together to prevent cross contamination or damage. In addition, bricks and concrete can be demolished without mixing with other materials such as windows and doors. This enhances the quality of dismantled bricks and concrete. Hence, selective demolition also reduces damages and polluted materials for recycling and reuse.

However, some factors are worth considering. Selective demolition may prolong the project period and induce higher cost which may deter developers from considering such strategy.

Reuse materials during Renovation

During a building life cycle, renovation within the building is another sources of building material waste generation. Figure 36 shows some examples of the green interiors renovation.

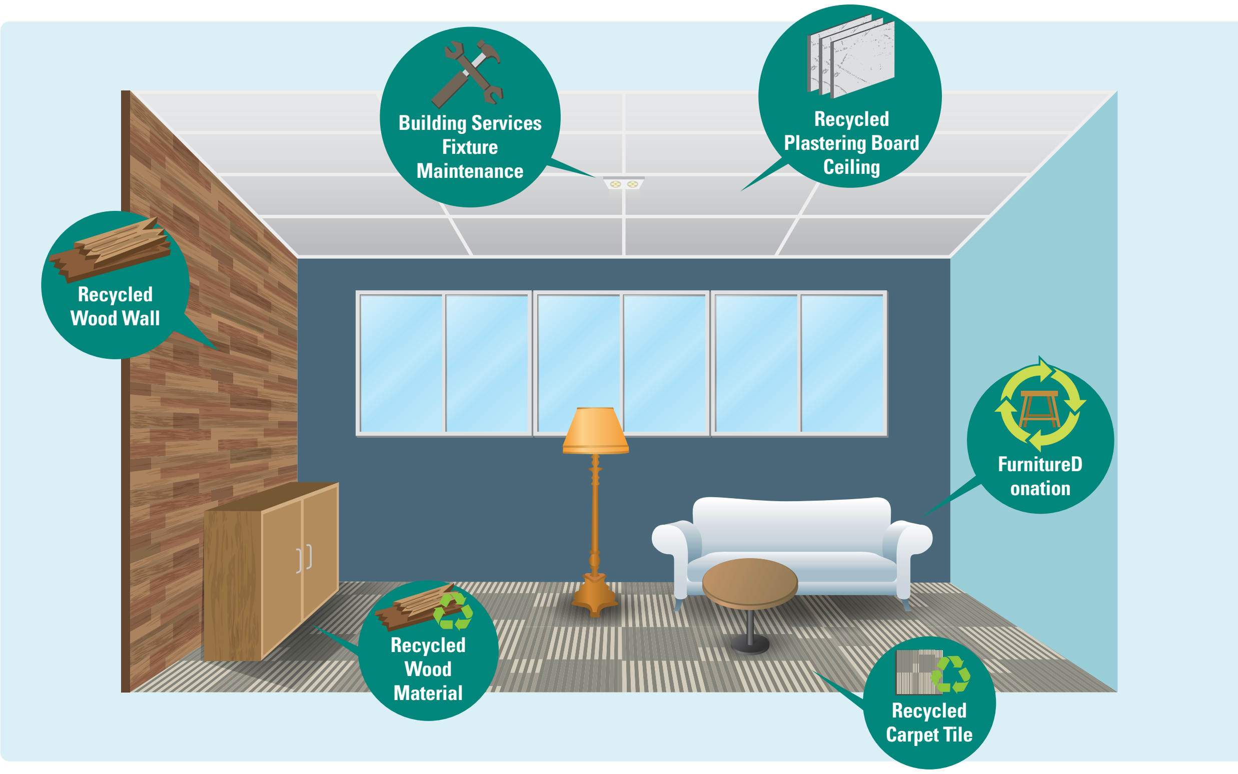


Figure 36 Example of green interiors renovation

Renovations of commercial buildings, such as office towers and shopping malls, are very common in. Waste generated from renovation includes as-fitted materials such as ceiling plastering boards, carpet tiles, walls and building services equipment. In building services retrofitting works, replacement of major equipment inside the building may require partial demolition of non-core structures, such as bricks and concrete.

BEAM Plus for Interiors Version 1.0 includes credits related to decoration and renovation. Under the Materials Aspects (MA) criterion, prerequisites require the installation of waste recycling facilities and the reuse of timber for temporary works. Besides, core credits concern about products chosen in renovation activities. Green products can, in general, achieve a higher rating.

MA P2	Minimum Waste Recycling Facilities	
MA P3	Timber Used for Temporary Works	
MA 2	Interior Component Reuse	3 credits
MA 3	Furniture and Partitions	3 credits
MA 6	Sustainable Flooring Products	4 credits
MA 7	Sustainable Ceiling Products	4 credits
MA 8	Sustainable Wall and Door Products	4 credits

Figure 37 Credits related to as-fitted interior elements from BEAM Plus Interiors

Reusing the interior decoration materials could help reduce the waste generated from renovation activities.

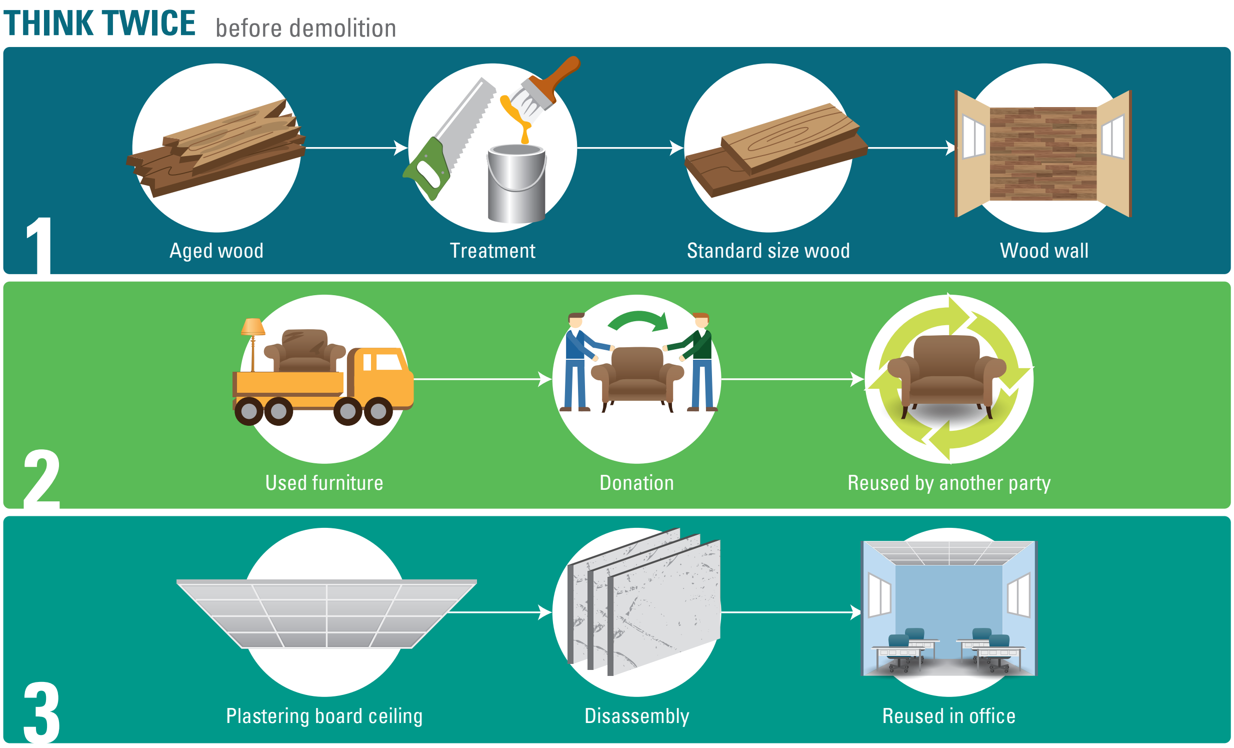


Figure 38 Reuse of interior decoration materials brought about from renovation

Wood is a common material used in furniture and flooring. During renovation, it could be reused as new interior as-fitted materials by trimming or cleaning.

Plastering board ceiling is popular in commercial and institutional application due to the regular size and ease for installation and maintenance. Aluminium tile is usually adopted for ceiling structure. Hence, it should be reused as much as possible until the quality and appearance is not acceptable.

The above examples demonstrate that some materials could still maintain their quality and values after being used for a long period. Hence, developing a set of quality guidelines are essential to ensure the materials can meet the quality for reuse.

The adoption of recycled materials has been gaining acceptance around the world. Recycled renovation materials, such as ceiling tile, wall tile and carpet tile are well received in oversea markets.

Nylon fibres, the main component of carpet, would be separated from bitumen backing during the carpet recycling process [Axion Consulting, 2018]. These separated materials can be used in a new carpet without sacrificing its quality. It provides clients with a plush, clean and eco-friendly alternative in flooring design.

Recycled Carpet Constitution Detail

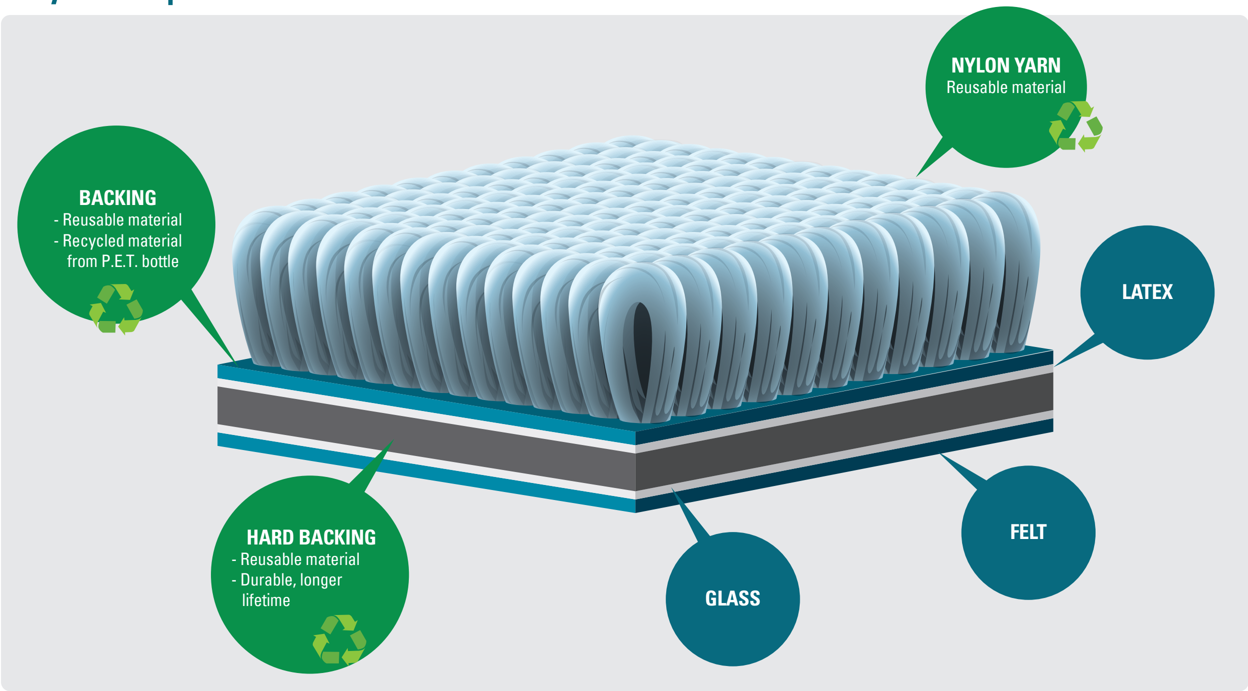


Figure 39 Section of recycled carpet

Figure 39 shows the isometric view of a portion of recycled carpet. Carpet tiles consist of a few layers of structure which are coming from recycled or reused material. The rigid backing could make the carpet more durable and a longer lifespan.

Donation of furniture and electronic appliances to charitable organisations is getting popular in recent decades. The collected furniture and appliances would be further donated to people in need. The EPD provides a list of organisations of furniture and electrical appliances recipients [EPD, 2015].

Sharing platforms are available in Hong Kong to encourage industry practitioners to reuse construction materials and furniture, for example, HK G-share, a free e-platform established by the HKGBC which encourages the public to share and reuse of useful resources. Through this platform, the HKGBC aims to raise the public awareness of waste reduction and the reuse of useful resources, reduce the burden of the landfills, and together build a greener Hong Kong.

Demolition Impact Assessment (DIA) 5.3

The building envelop and interior elements of a building might be damaged or deteriorated after being used for decades. Such damages and deterioration would definitely increase the difficulties in sorting and waste treatment process. Hence, a DIA as shown in Figure 40 should be performed before starting demolition works.

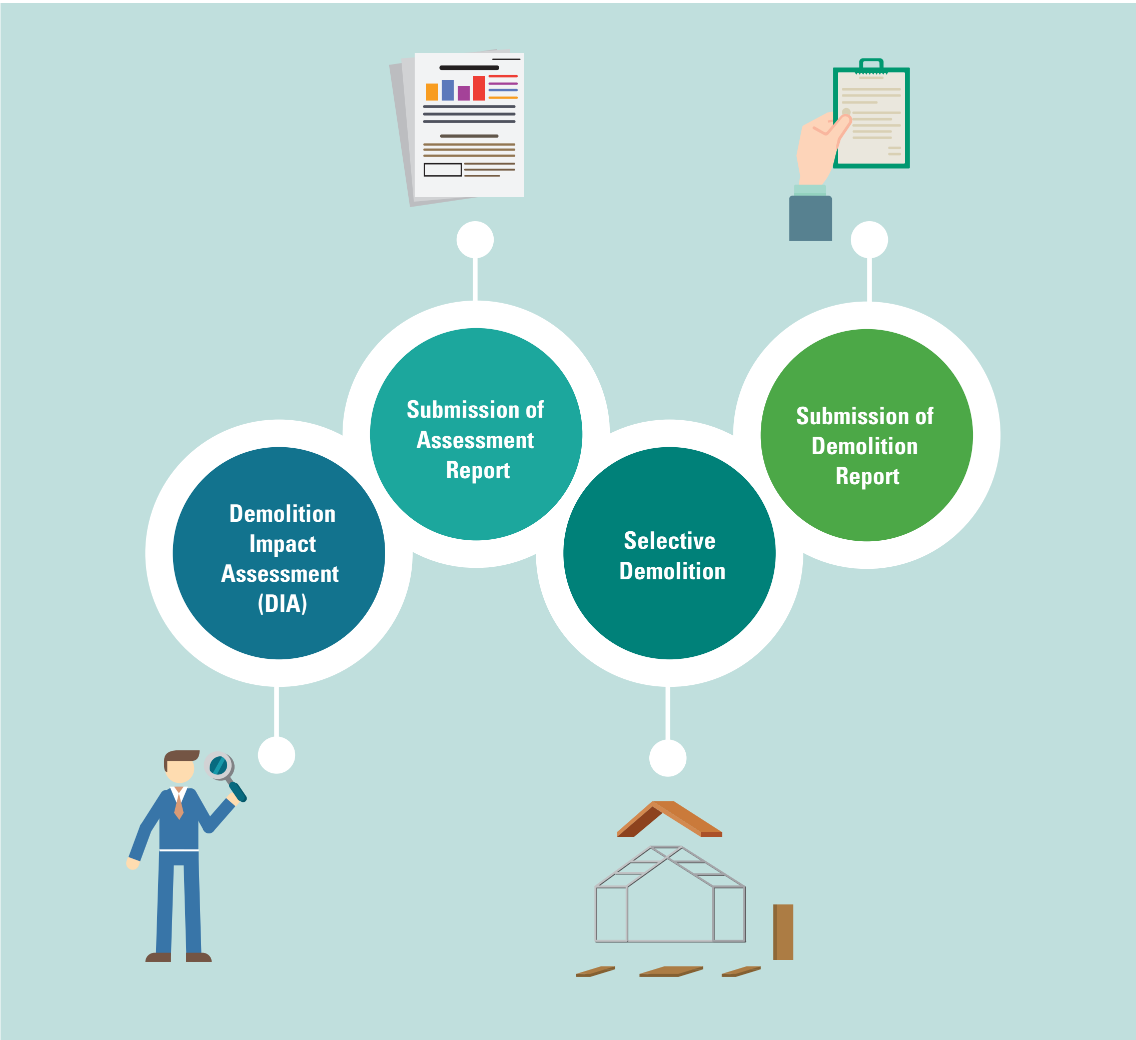


Figure 40 Demolition impact assessment conceptual flow diagram

i. Demolition Impact Assessment (DIA)

Quantity surveyor or building surveyor are the suggested profession to perform DIA before selective demolition. The amount of materials generated should be listed out as shown on the bill of quantities in building project. The assessment document should clearly state all the locations and dismantling treatments for all demolition materials. Apart from identifying the scope of work, the assessment should also establish working schedule and procedure with appropriate methods. Execution plan for labours should also be indicated in the assessment.

ii. Submission of Assessment Report

The assessment report should be submitted to clients and contractors for approval and negotiation if any specific requirement are to be included. According to assessment result, contractors could decide a suitable method on demolition and estimate the amount of building material waste that would be disposed. Part of the structure could be retained if the assessment clearly shows that the durability of structure is acceptable.

iii. Selective Demolition

As mentioned in Section 5.2, selective demolition should be adopted to execute the demolition process. Labours should refer to the instruction from the assessment plan or contract terms.

iv. Submission of Demolition Report

After demolition stage, a demolition report should be submitted to client and contractor for recording the amount of waste generated.

Waste Recycling

To recycle more building material waste, a better sorting is the key to success. Table 4 illustrates the use of recycled demolition materials in Hong Kong.

RECYCLED MATERIALS	USAGE
AGGREGATES	Road construction, foundation works
ASPHALT	Aggregate fill
EXCAVATED MATERIALS	Filling materials
EXPANDED POLYSTYRENE	Lightweight concrete for non-structural work
GLASS	Substitute for sand, aggregates and bricks
METALS	Reform / reshape metals
PLASTIC	Synthetic materials for landscaping
PUBLIC FILL	Land reclamation
PULVERISED FUEL ASH	Manufacture of concrete products
RUBBER	Manufacture of rubber slate tile

Table 4 Existing possible recycling path of different material

In general, aggregates, metal and pulverised fuel ash are three major materials for recycling. Metal is the most popular as it has great economic value after reshaping. Aggregates have a great potential but the recycled market is not well developed [Rao, Jha & Misra, 2006]. Majority of the recycled rubber and plastic were used in recreational facilities.

However, recycled products with low values (e.g. bricks, sand and plastic, etc.) are hurdles for future development. It discourages recycling companies to recycle building material waste even though some of them are recyclable.

To tackle the aforementioned problems, the industry should make effort in increasing the market value of the recycled products. Some suggestions are listed below and shown in Figure 41.

Recycle Policy & Quality Standard

One of the ways is to ensure the quality of the recycled products. Existing waste recycling policies should be reviewed. Reference includes the "Construction Waste Recycling Promotion Act" in South Korea as mentioned in Appendix. Under the law, construction companies are required to use recycled products under certain situations. Moreover, the quality of recycled products, such as recycled aggregates, are regulated by policies.

Government involvement

The Government could also involve in supporting recycling companies through various schemes. By doing so, financial incentives could drive and encourage companies to use recycled products. With greater demand for recycled products in the market, the market value of the recycled products would then be boosted.

Recycling facilities

More industry-led recycling facilities in Hong Kong should be employed in order to achieve a better amount of collection of recyclable materials. Moreover, by implementing different recycling facilities, it could help in logistics cost and materials storage from different construction sites.

Technologies

The latest recycling technologies should be introduced to Hong Kong in order to enhance the quality and diversification of the recycled products. BIM could act as a supplementary tool for investigating recycled product performance instead of traditional product such as recycled aggregates rather than reinforced concrete.

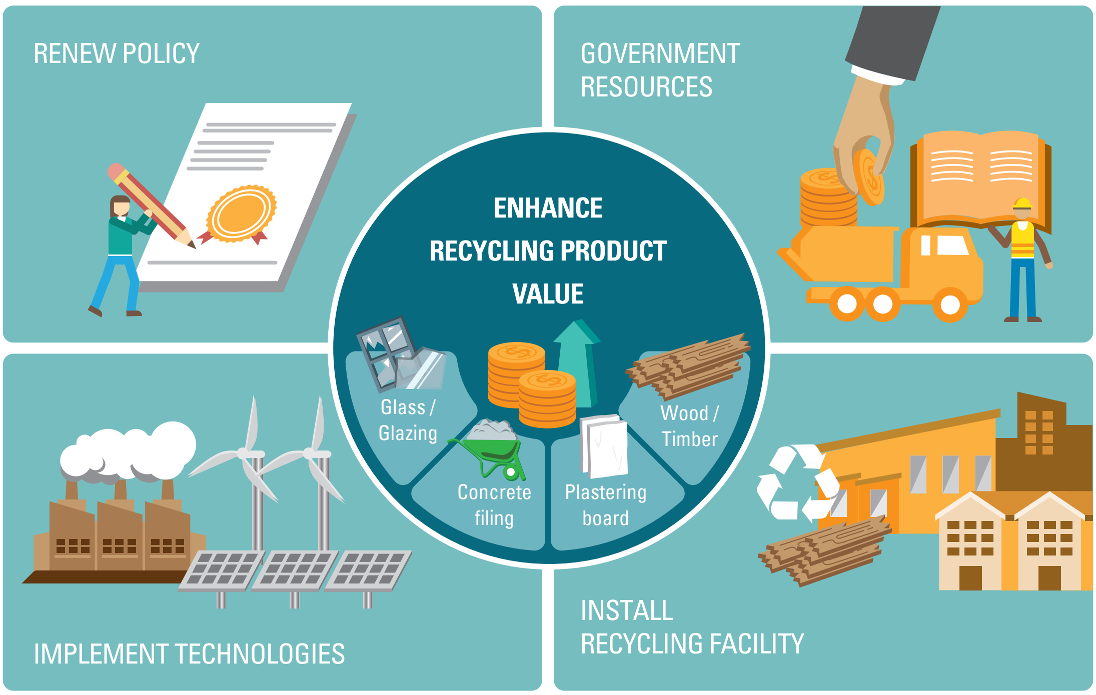


Figure 41 Enhancement of market value of recycled products

5.4 Case Study

EMSD Headquarters

The EMSD new headquarters in Kowloon Bay demonstrates the application of retainability on demolition project as shown in Figure 42. The EMSD new headquarters were converted by the former Hong Kong Air Cargo Terminal 2 building (HACTL 2). The new building is a seven-storey building comprising offices, vehicle workshops and electronics workshops with a gross floor area of 81,000 square metres. Converting and modifying the HACTL 2 building saves huge amount of energy and building materials in the construction of an otherwise new building.

Figure 42 Retainability application on demolition project – EMSD Headquarters

The project was completed in 2004, with the installation of new block and implementation of new exterior façade. Parts of the existing building which are not suitable for conversion were demolished. Additional work was done to retain the existing part of structure to lengthen the building lifetime. An additional floor (7/F) and a new metal roof were added to the new headquarters. The existing external walls of the main elevations are converted into environmental facades, with ventilated double-layered curtain walls for the office floors (6/F & 7/F) and metal sun shades for the workshop floors (G/F to 5/F).

The new EMSD headquarters building has been designed to make full use of the concrete structure of the HACTL 2 building as far as possible, by retaining most of the concrete and steel structure of the old building. The conversion has greatly reduced the use of energy and construction material as well as construction waste created in the process where the volume of construction waste saved can fill a four-storey building of the size of a football pitch.

Hong Kong Housing Authority (HKHA)

The HKHA carries out a sustainable practice throughout the demolition process. HKHA has started piloting BIM since 2006 which helped improve building quality by optimising planning and designs, improving coordination, and reducing construction waste and enhancing workers' safety. Professional and technical staff have accrued essential experience and mastered crucial techniques in BIM implementation. There were encouraging results emanating from recent breakthroughs in BIM application in the structural engineering field for demolition, excavation, volumetric precast works and foundation design in addition to the strategic introduction of BIM as a standard design tool for housing projects. BIM has now become one of HKHA's most important tools and platforms in the development of public housing projects. For example, simulation of demolition sequences of precast building in Lower Ngau Yau Kok Estate for effective site safety planning. Demolition planning and simulation of So Uk Estate helped to resolve the challenge on cantilever corridor and balcony, as well as the limited mechanical plant and equipment operation area.

CHAPTER 5 SUMMARY

STRATEGIES

Design for Disassembly (DfD)	• Enable reuse of component • Minimise virgin material use • Design with layer of change • Lengthen building lifespan
Demolition Planning	• Selective demolition • Reuse building materials during renovations • Guarantee efficient sorting
Demolition Impact Assessment (DIA)	• Clearly state all locations and dismantling treatments for all demolition materials • Establish a schedule and procedures with appropriate methods • Execution plan for labours

Chapter 6
Recommendations

The aim of this Guide is *TO ALERT THE PUBLIC, GOVERNMENT AND INDUSTRY ABOUT THE BUILDING MATERIAL WASTE PROBLEM AND PROVIDE ADEQUATE GUIDELINES IN MINIMISING BUILDING MATERIAL WASTE FOR THE HONG KONG BUILDING INDUSTRY.* A checklist is provided as a summary of the Guide and recommendations to the industry. Practitioners are encouraged to use the checklist to identify potential building material waste reduction strategies which can be implemented throughout the building life cycle.

INTEGRATED DESIGN

- Organise a team for each process and assign a role for process coordinator
- Involve Owner, Contractor, Facility Manager, and Environmental Specialist in early stages
- Select strategic processes for redesign
- Introduce the redesigned process into the business organisational structure
- Simplify new processes and train the team to efficiently manage and operate the process
- Adopt BIM with all design team members throughout the building life cycle
- Use of BIM to pinpoint potential issues (e.g. structural, architectural and building services clashes, budget tracking and cost related activities)
- Incorporate building material waste management plan to BIM model and set waste reduction goals and environmental plans in early stage
- Automate processes using information technologies (e.g. BIM, BMS, intranet)
- Use of BIM to link attribute data to support facilities management and building operation
- Incorporate BIM model with BMS

DESIGN FOR CONSTRUCTION

- Use of standardised design, volumetric precast components, mechanised construction technology and precast of parts and components
- Use of precast elements (e.g. façades, staircases, partition walls, parapet and slabs)
- Consider Design for Manufacture (DfM) and Design for Assembly (DfA)
- Choose the most cost-effective materials and processes
- Minimise the complexity of the manufacturing process
- Use of steel formwork instead of timber formwork
- Deliver components carefully and strategically with respect to site conditions (e.g. just-in-time delivery)

DESIGN FOR OPERATION & MAINTENANCE

- Design for adjustability, flexibility, refitability, convertibility, expandability and movability
- Share knowledge between the facility management and design professionals
- Transfer the as-built BIM model data into the facility management system (e.g. BMS)
- Run ongoing analysis of operational capabilities with BIM model

DESIGN FOR DEMOLITION

- Reuse building systems, component and materials
- Design building with layer of change - separate building systems
- Simplify structural, joint and connection design
- Design components to maximise the number of times they can be reused and designed to be easily broken down into individual materials for recycling
- Select building materials intended as recycling feedstock and are easily dismantled
- Consider selective demolition
- Conduct Demolition Impact Assessment (DIA)

Appendix

APPENDIX A
MANAGEMENT OF BUILDING MATERIAL WASTE

Building material waste is a by-product of construction activities. Minimisation of building material waste are advised to take place at the beginning of construction or demolition by adopting on-site sorting. Then, the waste will be sent to landfills, off-site sorting facilities and public fill reception facilities. Any reusable or recyclable materials will also be sorted out for recovery.

The aforementioned is the typical building material waste management flow. However, things may go a bit different in real life situation.

List of challenges in Hong Kong:

1. On-site sorting is unlikely to take place in Hong Kong as the scale of construction sites are usually too small. Also, there is no adequate time to carry out on-site sorting [Poon et al., 2001].

2. It is difficult to do building material waste recycling due to the lack of information. Limited information of building material waste recycler are available on the EPD's website (https://www.wastereduction.gov.hk/en/quickaccess/vicinity.htm). This leads to the low awareness among industry players.

3. HKGBC conducted focus group meetings with stakeholders of the industry and they were concerned about the quality of local recycled building materials since the recycled materials are being treated by relatively low technology. Such concern makes recycled materials become less attractive to buyers. Thus, there is no outlet for recycled products.

However, on-site sorting could still be conducted in a small construction site by better planning of using different rooms on lower floors for storing different building material waste in advance. Such practice requires longer time and more manpower which may prevent developers from adopting this method.

Moreover, the solution depends on the quality of building material waste. The higher the quality and the higher the chance for reuse/recycle, the lower the amount of building material waste sent to landfills and public fill reception facilities. Meanwhile, if more public fill could be reused in building projects, we could help reduce the pressure of public fill reception facilities.

Off-site Sorting

There are two temporary building material waste sorting facilities in Tuen Mun Area 38 and Tseung Kwan O Area. Both are located near the public fill reception facilities. As the charge of sorting facility (HK$175/tonne) is cheaper than landfill (HK$200/tonne), when the building material waste contains more than 50 percent by weight of public fill, there are economic incentives for the contractor to send it to the sorting facility.

The objective of off-site sorting is to divide mixed construction waste into inert and non-inert waste. Through the off-site sorting process, metallic waste can be removed and different size of aggregates can be separated.

Figure 43 shows the operation process in off-site sorting facilities in Hong Kong.

Figure 43 Off-site sorting practice in Hong Kong

There are three major functions throughout the off-site sorting process:

i. Concrete aggregates categorisation

Treatment plants are used to classify the aggregate size, from less than 50mm to 250mm in diameter. This categorisation not only sorts out the aggregates for reuse and recycle, but also saves time and labour cost comparing to manual sorting.

ii. Metallic material separation

Metal recycling is common in Hong Kong because of its market value. Structural rod or cables can be recycled at low cost, for example, by cleaning and melting. A magnetic separator is then used to separate all metal scrap or pieces.

iii. Non-inert waste sortability enhancement

All residual materials after previous processes will be treated in the final step. After the inert waste is removed, the remaining part will be sorted by labour manually. All residue non-inert waste will be transported to landfill.

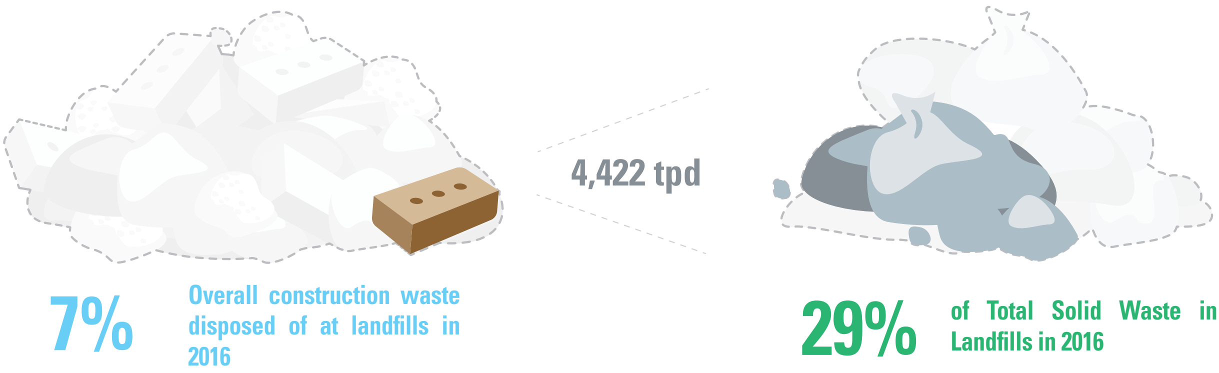


Figure 44 Disposal and reuse of overall construction waste in 2016
(Source: Monitoring of Solid Waste in Hong Kong – Waste Statistics for 2016)

Figure 44 shows that most of the construction waste were sent to public fill reception facilities or transferred to projects for direct reuse and only 7 percent was sent to landfills. However, this 7 percent constituted 29 percent of total solid waste at landfills in 2016.

Landfills Capacity:

(Source: Powerpoint named "Public Fill Management in Hong Kong" by Civil Engineering and Development Department)

Figure 45 Map of Different Construction Waste Treatment Facilities in Hong Kong

There are three strategic landfills in Hong Kong, namely West New Territories (WENT) Landfill, South East New Territories (SENT) Landfill and North East New Territories (NENT) Landfill.

Construction waste generated from islands will be collected at Outlying Islands Transfer Facilities (OITF) and further shipped to WENT.

From 6 January 2016 onwards, the SENT Landfill at Tseung Kwan O has been designated to receive only construction waste to address the odour problem [EPD, 2016].

Owing to the rundown of reclamation projects in Hong Kong in recent years, the surplus public fill problem has reached an acute stage where available reclamation projects are unable to accommodate all public fill. The Government has been relying on fill banks to provide temporary storage for the fill material. As local reuse cannot absorb all public fill generated in Hong Kong, the Government entered into an agreement with the relevant Mainland Authority for delivery of surplus public fill to a receptor site in Taishan, Guangdong since 2007.

Currently, construction waste are disposed of at different treatment facilities including public fill reception facilities, sorting facilities, OITF and landfills.

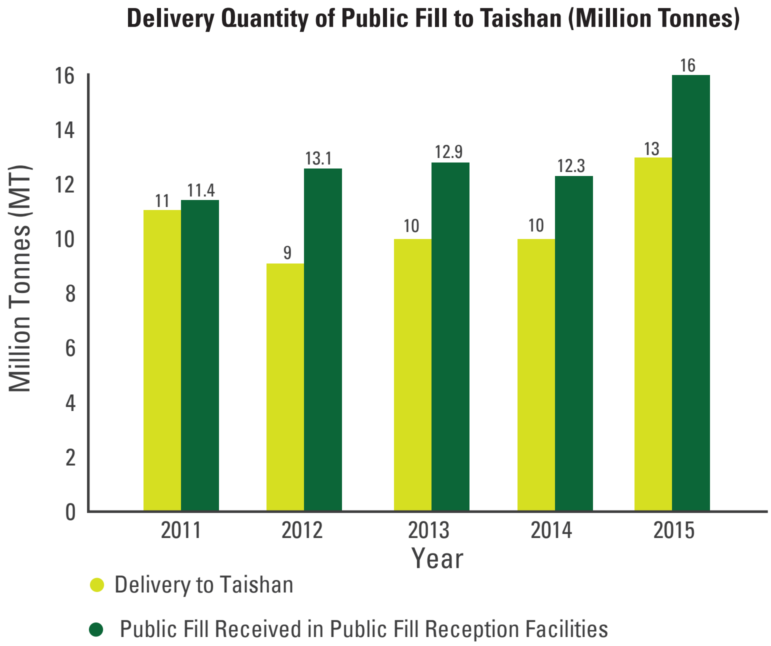


Figure 46 Quantity of public fill delivered to Taishan from 2011 to 2015 (Mok, 2016)

Figure 46 illustrates that Taishan had been an important destination for receiving surplus public fill in recent years. From sustainability point of view, while the fill materials delivered have been for gainful reuse at the destination regions, concerted efforts should also be made locally in Hong Kong to encourage and help the construction industry to reduce and reuse C&D materials as far as possible.

Material Management

Symmetrical material management is regarded as an effective way to reduce waste of materials in the construction industry. This can be achieved by using Radio Frequency Identification (RFID) and Geographic Information System (GIS) technologies. The details of each application will be discussed in the following section.

Radio Frequency Identification (RFID)

Radio-frequency Identification (RFID) refers to the use of radiofrequency electromagnetic fields for a two-way radio transmitter-receivers by sending and receiving signal through the tags or labels attached to the objects. Its purpose is to identify and track the objects by transferring data from a tag to a reader.

Figure 47 Gammon installed RFID chips in the curtain wall panels, which can be tracked from the process of manufacturing, assembly, delivery and installation. With clear and full traceability, real time data is provided to the operation team and improve the materials management at congested site (Gammon Construction Limited, 2016).

Geographic Information System (GIS)

A Geographic Information System (GIS) is a system designed to capture, store, manipulate, analyse, manage, and present spatial or geographic data. GIS can refer to a number of different technologies, processes, and methods. It is attached to many operations and has many applications related to engineering, planning, management, transport and logistics, insurance, telecommunications, and business. Diverse applications of GIS include facilities management and planning, service management and planning, post code queries about service locations, analysis of property, such as flood risk and property values, demographic analysis, and environmental impact analysis [Designing Buildings Limited, 2017].

APPENDIX B

INTERNATIONAL REVIEW ON THE CURRENT STATUS, PROBLEM AND SOLUTION OF BUILDING MATERIAL WASTE

Apart from Hong Kong, treating building material waste is also a growing environmental issue in various developed countries and regions, especially when land is becoming a scarce resource and landfill is no longer an effective solution.

Different countries and places have various policies to minimise the problem, yet many of them may not be relevant to Hong Kong as their economy and society, nature of building material, scale of construction and land availability are hugely different from Hong Kong. Nevertheless, we can make reference from nearby places including Singapore, South Korea and Taiwan as these places share some similarities in economic and geographical characteristics. They also have been developing different strategies to tackle building material waste problem by emphasising on reusing and recycling of construction debris to minimise the amount being disposed of to landfills and reducing solid waste.

SINGAPORE

Situation of Construction Waste Management

Similar to Hong Kong, Singapore is a densely populated country with 7,697 people per km2 [Census and Statistics Department (C&SD), 2018]. Construction activities have grown rapidly in Singapore as its Construction Gross Domestic Product (Construction GDP) value in 2016 was approximately 19 billion Singapore dollars [Statista (2018)]. yet land is very limited in Singapore and the treatment of construction waste is a big problem for the country. Although Singapore is not producing as much construction waste as Hong Kong, their construction waste recycling rate reaches 99 percent, which is among the best performers of the world economies [National Environment Agency, 2018].

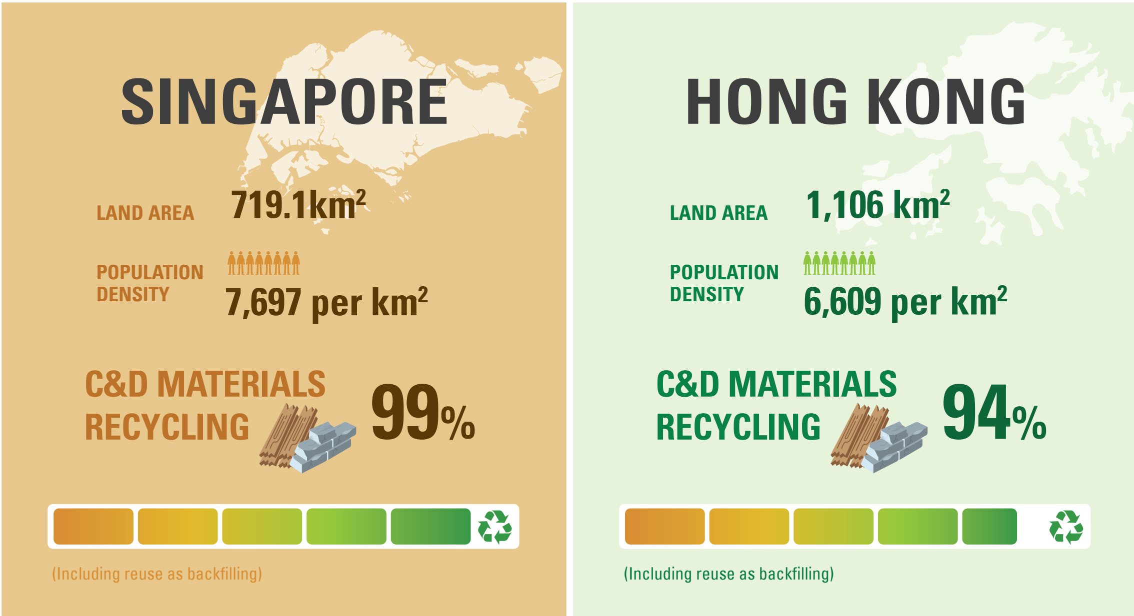


Figure 48 Comparison of Singapore and Hong Kong on geographic information and building material waste recycling rate (Including building materials reused for backfilling) (Zero Waste Singapore, 2015)

Singapore and Hong Kong are similar to each other on construction activity growth in the last decade. According to Trading Economics (2018), the Construction Gross Domestic Product (construction GDP) in Singapore and Hong Kong both doubled in 2016 when compared to 2006.

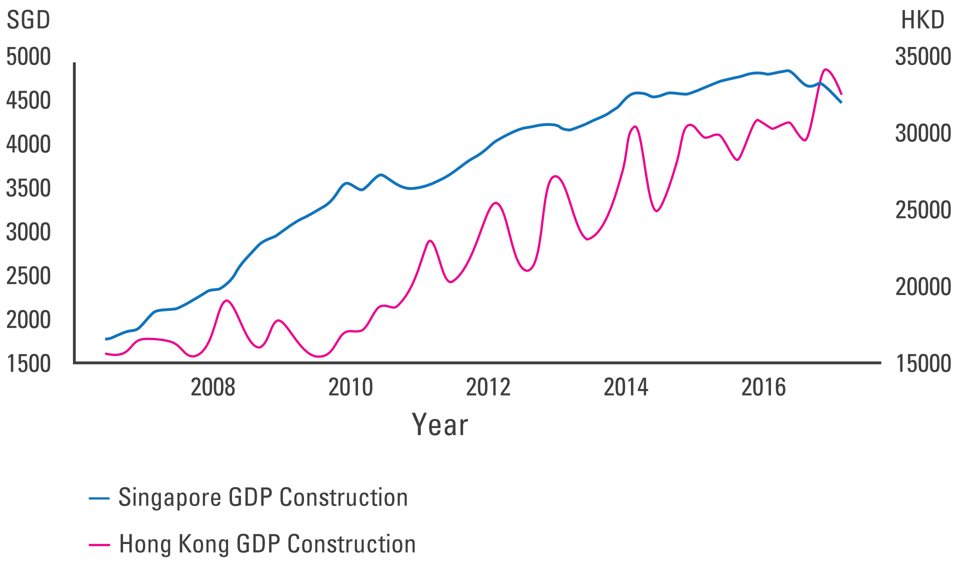


Figure 49 The Construction GDP of Singapore and Hong Kong from 2006 to 2017 (in SGD and HKD respectively) (Trading Economics, 2018)

Remarks: 1 SGD=5.63025 HKD

Construction Debris

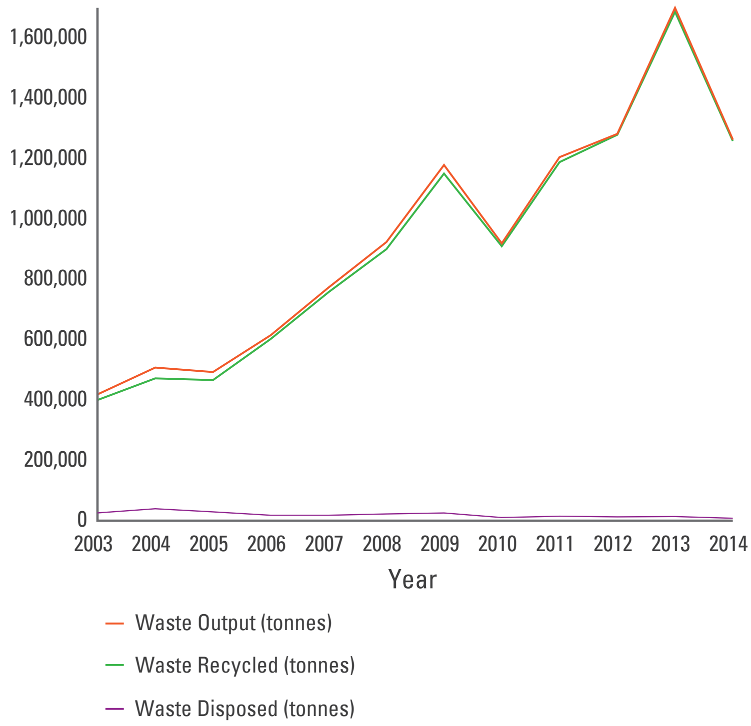


Figure 50 The construction waste generation and recycling in Singapore from 2003 – 2014 (Zero Waste Singapore, 2015)

The amount of construction debris in Singapore soared from 600,000 tonnes per year in 2006 to 1,700,000 tonnes per year in 2013, urging the Government to put emphasis on construction materials recycling to lessen the pressure of the only landfill for disposing non-incinerable waste in Singapore. Figure 50 illustrates that in Singapore, the amount of waste generated is nearly equal to the waste recycled [Zero Waste Singapore, 2015].

Market Development for Recycled Construction Materials

A) High Landfill Disposal Cost

Waste disposal cost is one of the major concerns for building projects. In Singapore, the Semakau Landfill is the only landfill used for disposing non-incinerable waste. High landfill disposal cost gives rise to the development of private construction materials recycling industry in Singapore. Developers and contractors are more willing to recycle construction materials in a more intensive manner and at a relatively lower cost, providing a business environment for the private recycling industry to develop and capital for new technologies.

	SINGAPORE	HONG KONG
Construction GDP (Million HK$)	115,184	110,321
Population	5,535,000	7,309,700
Construction GDP per capita (HK$)	20,810	15,092
Landfill disposal cost (HK$ per tonne)	450	125
Landfill disposal cost / Construction GDP per capital	2.1%	0.8%

Table 5 The Construction GDP per capita (HKD) and landfill disposal cost of Singapore and Hong Kong in 2015

There may be insufficient economic incentive for developers and contractors to put effort in recycling rather than simply sending them to landfills [Yu, Poon, Wong, Yip and Jaillon, 2013]. There are only two sorting facilities, owned by the Government, responsible for recycling and no scaled private recycling companies, making Hong Kong ineffective in minimising the disposal of building material waste.

B) Landfill disposal charges

In Singapore, the cost of disposing waste to landfill and incineration plants is approximately HK$450 per tonne [National Environment Agency, 2018], while the disposal cost in Hong Kong is just HK$200 per tonne after adjustment with effect from April 2017 (EPD, 2017a). With reference to the similar Construction GDP per capita among two regions, the landfill disposal cost in Singapore is much higher than Hong Kong. Continued monitoring of the charging scheme is necessary and the amount of construction waste sent to landfills should be monitored for a period of time to see if a drop of construction waste disposal will be observed for assessing the effectiveness of the adjusted charges.

C) Market for recycled materials

The recycling of C&D materials in Singapore is led by the private market. In 2007, the Indonesia Government imposed a ban on the export of sand to Singapore, which stunned their construction industry as sand is an important composition of concrete and 90 percent of sand was imported from Indonesia [Holcim, 2017]. The policy triggered the transformation of the industry to invest in recycling concrete debris to Recycled Concrete Aggregates (RCA) as much as they could and paved the way for the recycled construction materials market.

C&D waste in Singapore is collected by general waste collectors which are licensed by the National Environment Agency of Singapore. The materials will be sent to private recycling companies to recover useful materials such as plastics, paper, wood and ferrous metals by means of labour or magnetic separators. Concrete, bricks, gravel and stones extracted from the sorting process will then be transferred to other recycling facilities. These materials will be crushed and screened according to its size and become RCA of different sizes for future construction activities. The RCA being made cannot be used as structural materials, however, it can be used to make concrete products such as precast concrete blocks, drains and road kerbs instead.

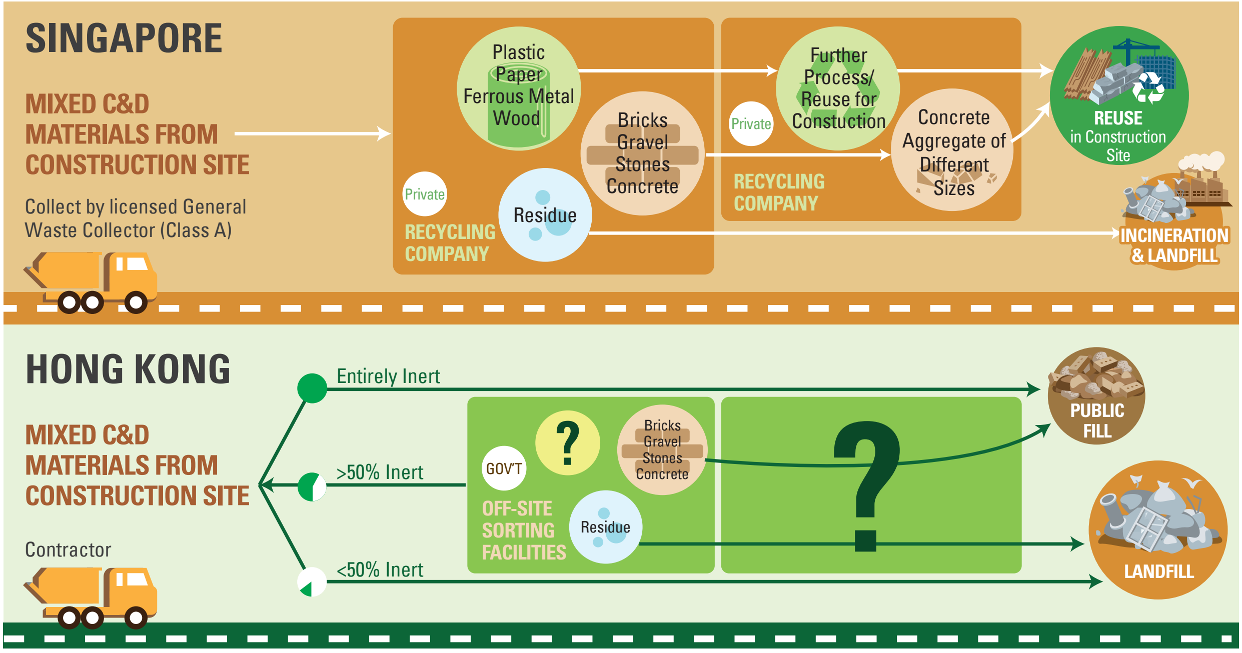


Figure 51 Comparison of C&D Materials Management Practices in Singapore and Hong Kong

The Singapore Government has also made efforts in supporting recycling companies by means of funding support, which lands are ensured for the setting up of new C&D materials recycling facilities and budget is allocated for new recycling technologies under the Innovation for Environmental Sustainability (IES) Fund.

In Hong Kong, the recycling of construction materials is mainly facilitated by the Government. Building material waste in Hong Kong is mainly categorised by inert materials content. In fact, the majority of inert materials are used as fill materials.

Debris mixture with more than 50 percent inert construction materials will be sent to sorting facilities for separating inert portion from mixed waste for reuse as fill materials. Other construction waste with less than 50 percent inert materials content, containing materials such as wood, glass, office equipment and furniture will be sent to landfill for disposal. 137 tonnes per day of industrial wood were being disposed of at landfill in 2016, which is around 15 percent of the daily industrial waste being sent to landfill [EPD, 2017b], leaving a great room for improvement for a more thorough recycling. Without incentives, the driving force for recycling construction materials is still low in the construction industry in Hong Kong.

D) Encouragement of Prefabrication

Prefabricated building components help reduce time, waste and on-site labour. Singapore is hot and humid throughout the year. The benefit of adopting prefabrication is more notable as on-site construction works are always hindered by frequent precipitation.

Construction sites adopting prefabricated components can reduce construction debris from certain types of wet-trade activities such as concreting, rebar fixing, plastering, screeding and tiling, by minimising the cut-off wastage and usage of moulds on-site [Tam, V. W. Y., Tam, C. M., Chan & Ng, 2014]. The off-site prefabrication plant allows the building components to be made under a controlled environment and by skilled labour, hence improving the quality and production efficiency. As more specific and sophisticated mechanics could be applied to off-site factories, less cut- off wastage and debris will be produced and minimise the waste generation as a whole.

The Singapore Government has paid effort in promoting prefabrication. The Building and Construction Authority (BCA) has introduced the Buildable Design Appraisal System (BDAS), a design scoring system to assess labour usage and productivity in construction sites. Projects with prefabricated building components can attain a higher "Buildability Score" which encourages building designers to consider using prefabricated products during design phase.

The buildability requirement has been made mandatory to all the new building projects since 1999 by the Government to further promote prefabrication to the private sector. Apart from the scoring system, the Government has also introduced training programmes such as precast concrete components erection and blocks installation to educate workers in performing prefabrication works. Common precast components including staircases, water tanks and light-weight partition panels. The use of prefabricated bathroom unit has been made mandatory for all non-landed residential Government Land Sale sites starting since Nov 2014.

In Hong Kong, the BEAM Plus assessment for New Buildings has taken consideration into prefabrication in materials aspects. Credits will be given to projects adopting prefabrication in building elements such as façades, staircases, balconies, footbridges, etc. However, since it is not a must for building projects to be registered with BEAM Plus in Hong Kong, the use of prefabricated products in private sectors is yet to be fully adopted by the industry. Only the Hong Kong Housing Authority and a few developers are using prefabricated products during construction.

Figure 52 Use of prefabricated building components in construction sites

SOUTH KOREA

Situation of Construction Waste Management

The construction waste generated in South Korea is in a rising trend. In 2012, South Korea produced 186,629 tonnes of construction waste per day, which is 155 percent of the construction waste produced in 2002. Although the recycling rate of construction waste in South Korea reaches 97.2 percent, yet most of the materials are being used as mounding and backfilling and only 32.3 percent materials are being recycled to generate high value-added RCA in 2012 [Ministry of Environment, 2017]. The situation is similar for Hong Kong, which 89.4 percent of construction waste are being used as backfilling and only 4 percent of materials are being recycled to produce useful products. To further improve the sustainability of the construction waste generated, policies should be introduced to boost the generation of RCA for future construction uses.

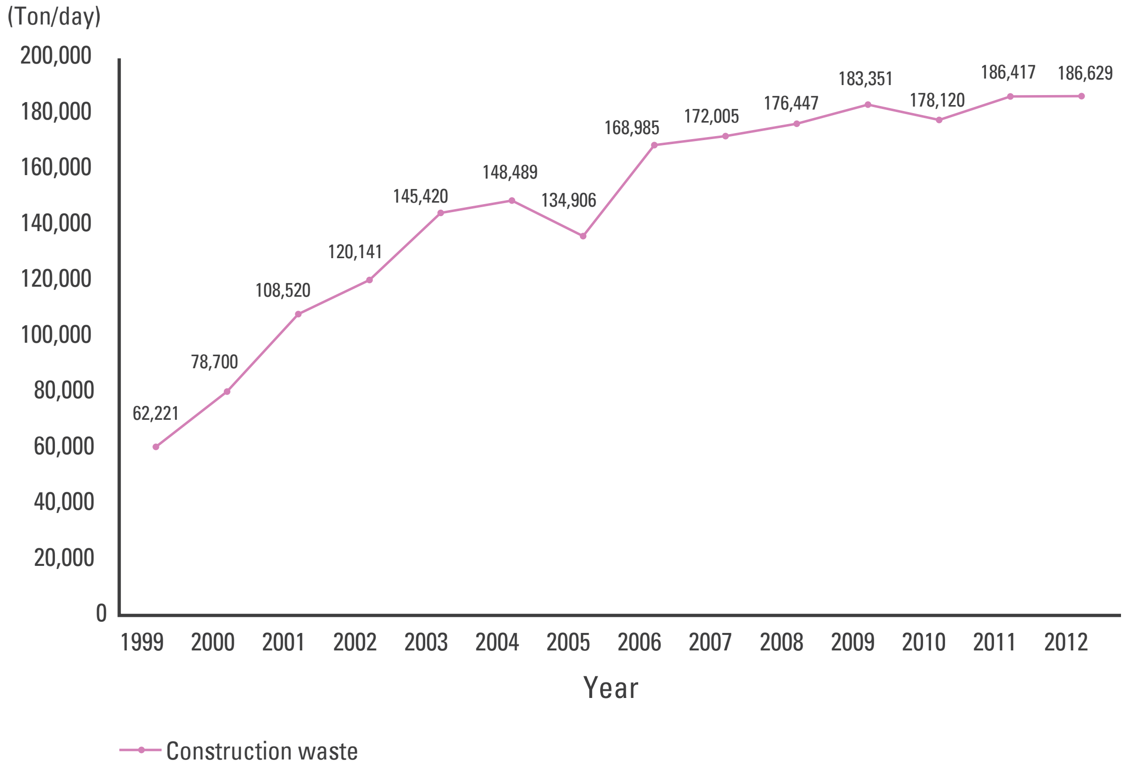


Figure 53 Trend of construction waste generation in South Korea from 1999 to 2012

Treated amount (ton/day)	Landfill	Incineration	Recycling	Total
South Korea	4,118 (2.2%)	1,016 (0.5%)	181,493 (97.2%)	186,617 (100%)
Hong Kong	3,440(5%)	0 (0%)	63,538 (95%)	66,978 (100%)

Table 6 Status of construction materials treatment in South Korea and Hong Kong in 2012

Policies for Construction Waste Management in South Korea

A) Construction Waste Recycling Promotion Act

Major problems of promoting RCA include the lack of market and reluctance of market players. To ensure RCA is being adopted in the construction industry, the Ministry of Environment (MoE) of South Korea has established the "Construction Waste Recycling Promotion Act" in January 2015 to regulate the industry to manage construction waste in an environmental friendly manner and produce high value products by recycling construction debris.

Under the Act, construction companies are required to use RCA in building three types of infrastructures including new road construction or road expansion works for more than 4km, industrial park construction for more than 150,000km2 and sewage treatment facilities construction. With the new policy, the recycling rate of concrete debris in making RCA has risen from 32.3 percent in 2012 to 45 percent in 2016 [Ministry of Environment, 2017], which encouraged the high value-added waste recycling industry in South Korea.

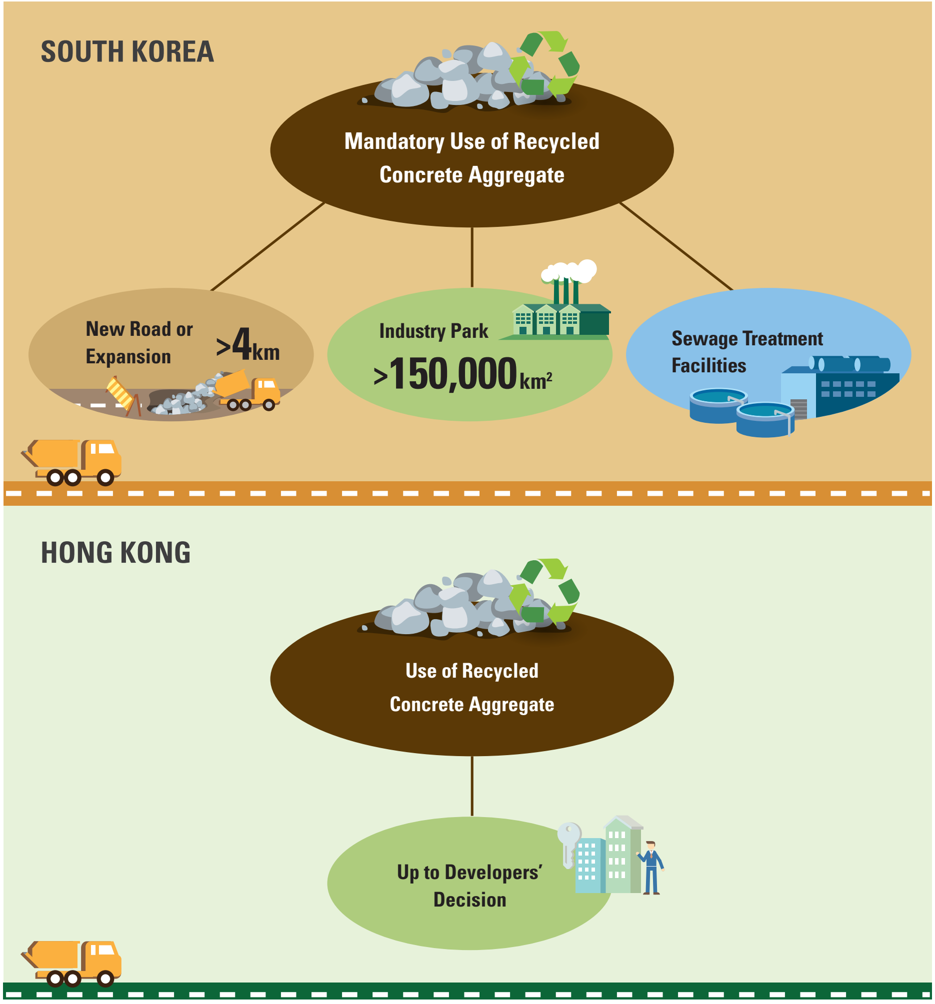


Figure 54 Types of construction require the use of recycled concrete aggregates (RCA)

Policies for Construction Waste Management in South Korea

B) Quality Certification System for Recycled Concrete Aggregates

Major problems of promoting RCA Low quality RCA can only be used to pave roads or ground surfaces. There is a concern that RCA may contain contaminated materials, such as chloride from flushing water, which will affect the quality and durability of concrete. As the structural frame of a building cannot be repaired easily, using RCA as structural concrete materials is not a good option.

Not only roads can be repaired more easily with RCA, there is also another concern that RCA is having a higher hydration level which may hinder its performance as structural concrete materials. Hence, RCA have to meet standards and be certified to ensure it has sufficient compressive strength to be adopted as structural materials. The Government of South Korea has introduced several certification standards including "KS F 2573" in 1999, which regulates the quality of recycled aggregates for concrete [Choi, 2017]. It defines the quality and quantity of RCA composition allowed in concrete products.

<table>
<tr><th rowspan="2"></th><th rowspan="2">Compressive strength (MPa)</th><th colspan="2">Aggregates</th><th rowspan="2">Typical Useage</th></tr>
<tr><th>Coarse Aggregates</th><th>Fine Aggregates</th></tr>
<tr><td rowspan="2">SK</td><td>21-27</td><td rowspan="2">Natural coarse aggregates and recycled coarse aggregates</td><td>Natural fine aggregates olny</td><td>Column, girder, slab, load-bearing wall, etc.</td></tr>
<tr><td>< 21</td><td>Natural fine aggregates and recycled fine aggregates</td><td>Concrete block, road base, filler material for concrete, etc.</td></tr>
<tr><td>HK</td><td colspan="4">No regulatory requirement</td></tr>
</table>

Table 7 The requirement of RCA South Korea

Although the quality of RCA has been studied in Hong Kong for some years [Poon & Chan, 2007], no recognised quality certification scheme has been rolled out for the industry as a reference to adopt RCA in building projects, which hinders the potential of the RCA manufacturing industry development to reduce the amount of concrete debris for public filling or landfilling.

C) Electronic Information System on Waste Monitoring and Recycling

Allbaro System

Allbaro System is a legal database that monitors and manages all kinds of waste information, including construction waste, from discharging, transportation to treatment. Developed in 1999, the Allbaro System monitors waste processing with the help of RFID and GIS [Korea Environment Corporation, 2017a]. It serves as a tracking system to prevent illegal dumping of construction waste, and a verification system to monitor all information submitted by waste generators and collectors in real time.

Recyclable Resources Market

Recyclable Resources Market is an online portal system to provide a marketplace for waste recycling. It provides information to both waste suppliers and customers on materials distribution, quality and transactions in order to promote the recycling of used products and waste materials. The portal system is also linked with the Allbaro System to obtain waste materials location so that the customers can identify the closest yet available materials. Until September 2013, the system has 69,000 users and 234,000 traded items [Korea Environment Corporation, 2017b], generating economic benefits of approximately 3.3 billion US Dollars [Shin, 2013].

TAIWAN

Situation of Construction Waste Management

In Taiwan, the C&D materials are classified into two categories namely "construction earthwork" and "construction waste" which are managed by two authorities respectively as shown in Figure 55. Construction earthwork includes bricks, tiles, concrete, sand, etc. while construction waste includes wood, glass, ferrous metals, plastics, etc.

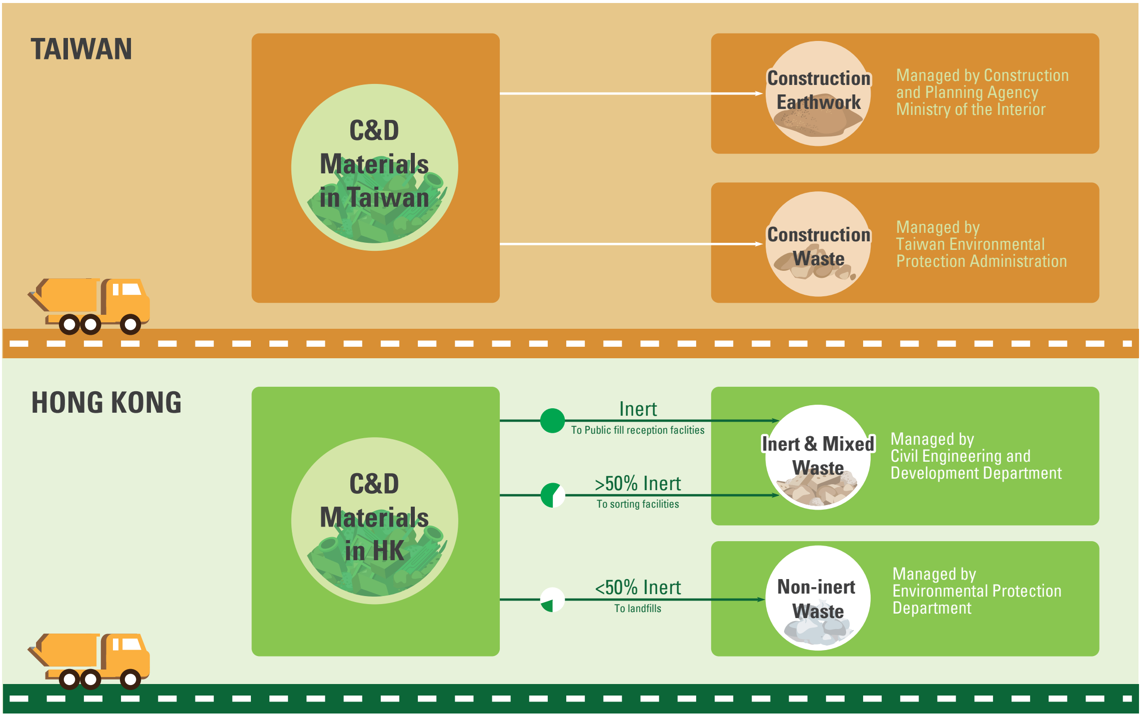


Figure 55 The classification and respective management of C&D materials in Taiwan

Most of the construction earthwork in Taiwan can be recycled to useful resources for constructions and each year there is about 8 to 14 million tonnes of construction earthwork being generated [Lai, Yeh, Chen, Sung & Lee, 2016]. Unlike the practice in Hong Kong, where most of the construction materials recycled are used for backfilling, earthwork materials in Taiwan will be sent to recycling facilities and being separated and sorted into different useful materials. Fine aggregates, sand or soil, gravel, grain and pebble can be sorted out after screening and crushing to recover useful materials. A total of 126.5 million tonnes of the materials has been treated in 156 recycling plants in Taiwan until 2014. The recycling industry in Taiwan has been developed with subsidies from the Government. The recycling system, named the "4-in-1 Recycling Programme", is the cooperation of waste producers, local Government, recycling businesses and the Recycling Fund Management Board.

Ferrous metals, paper and plastics in construction waste can be separated by using magnetic separation and air classification processes. Approximately 1.2 to 1.9 million tonnes of construction waste is being generated in Taiwan each year and almost 80 percent of the waste materials can be reused and recycled by 64 treatment facilities.

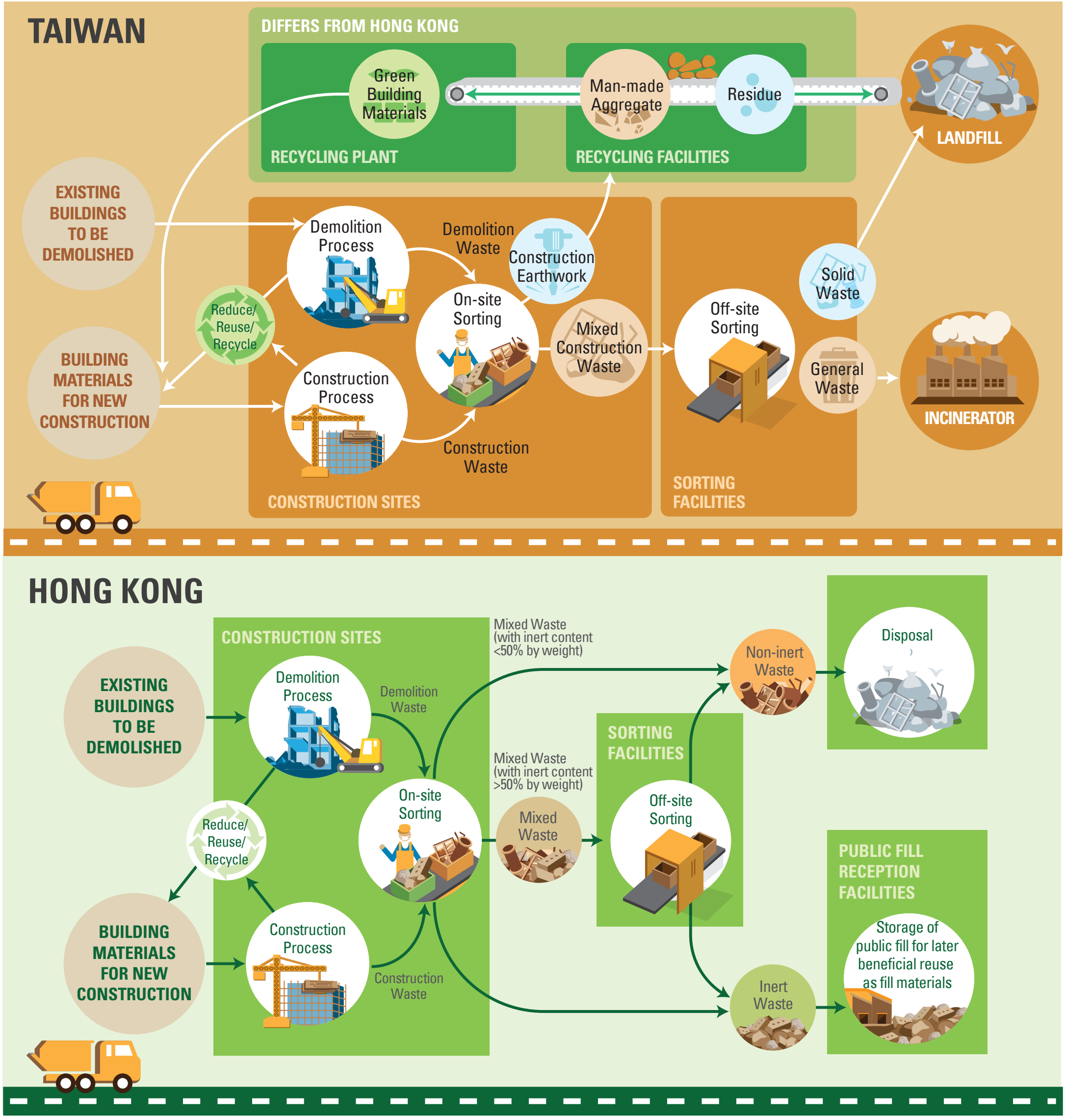


Figure 56 The comparison of C&D materials management practices in Taiwan and Hong Kong

Policies for Construction Waste Management in Taiwan

Industrial Waste Report and Management System (IWRMS)

The Taiwan Environmental Protection Administration (TEPA) has established the Industrial Waste Report and Management System (IWRMS) since 2000, a web portal to register and analyse construction materials information in the full cycle from generation to disposal. It connects TEPA and local Environmental Protection Bureau with all stakeholders in construction waste management such as generators, transporters, treatment facilities and disposal sites to monitor every aspects of the materials treatment process using GPS.

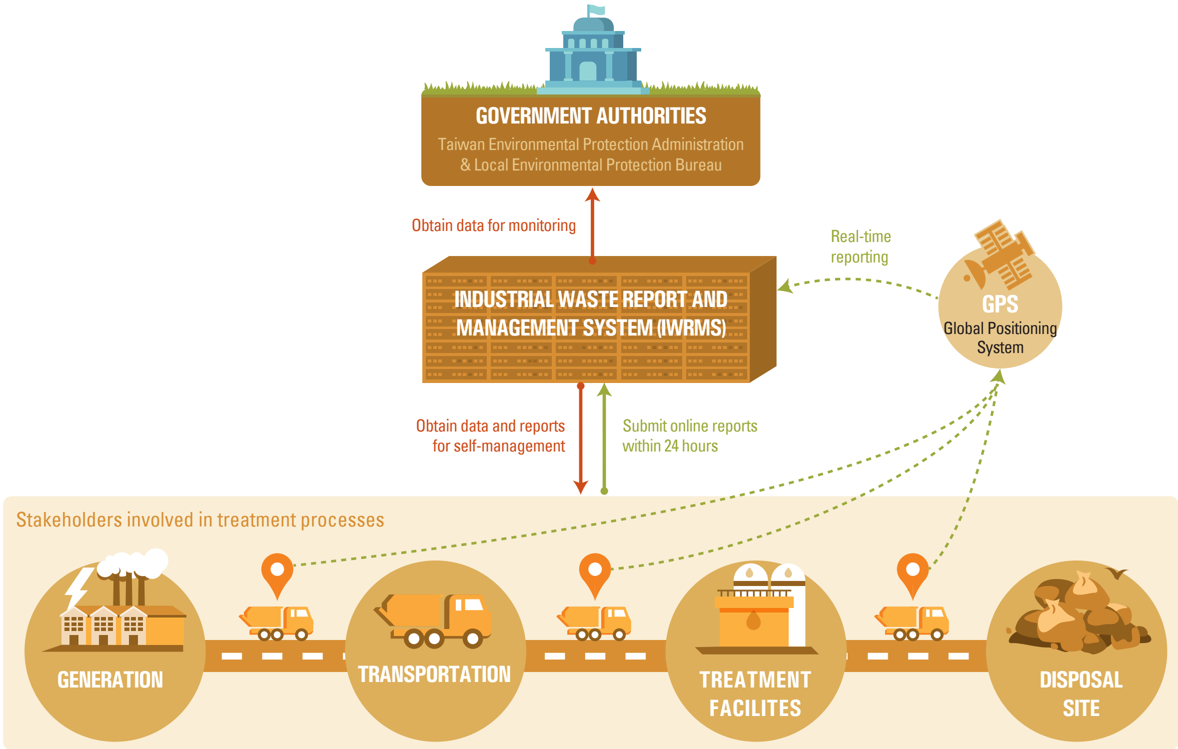


Figure 57 Concept map of Industrial Waste Report and Management System (IWRMS) in Taiwan

The related parties are required to file online reports within 24 hours for the information of C&D materials being shipped and treated. Apart from information registration, the parties can also make use of the system to analyse the data and generate reports for their self-management and improvement. As in 2013, more than 30,000 C&D materials treating units have been required to report data using the system which covered 80 percent of all the waste generated in Taiwan [Houng & Cheng, 2013].

In Hong Kong, the use of information system in construction waste management is not as comprehensive as Taiwan. One of the reasons is the lack of precise data collection in every single process of waste transportation, such as using the GPS for trucks to monitor the transportation process and avoid fly-tipping.

	Experience Learnt	Recommendations for the Government and Relevant Organisations	Experience Learnt From
A	**Elevate landfill disposal cost of C&D materials** • Drive industry to minimise, reuse and recycle C&D materials to reduce cost	1. Continued monitoring of the charging scheme as well as the amount of construction waste landfilled is necessary for assessing the effectiveness of the adjusted charges 2. Discuss the introduction of incinerator to reduce waste volume 3. Review the penalty for illegal dumping to better enforcement	Singapore (Table 5)
B	**Develop recycled C&D materials market** • Provide incentives for the development of C&D materials recycling private market and investment in technology • Increase the fineness of recycling	1. Provide subsidies to recycling companies to encourage the adoption of new C&D materials treating technology 2. Establish regulations to facilitate the use of recycled products from C&D materials in constructions 3. Develop quality accreditation system to ensure the quality of recycled products	Singapore (Fig. 54)
C	**Promote prefabrication** • Reduce cut-off wastage during on-site moulding • Improve quality of building products and enhance work efficiency	1. Promote the use of prefabricated building components in private sector	Singapore (Fig. 55)
D	**Develop reuse and recycle timetable and target** • Set up requirements for different types of construction works in using recycled concrete aggregates	1. Develop the timetable and target for the developers to follow and use reused and recycled materials in different construction works	South Korea (Fig. 56)
E	**Develop reuse and recycle requirement** • Introduce several standards for recycled concrete aggregates	1. Set up regulations and standards on the quality of reused and recycled materials	South Korea (Table 7)
F	**Centralised information system** • Share information among the stakeholders and encourage the facilitation of online C&D materials trading market • Improve stakeholders' performance in C&D materials management • Prevent fly-tipping issue	1. Establish real-time monitoring platform on C&D waste management by adopting GPS and RFID technology for waste transportation 2. Promote the use of BIM and BMS	Taiwan (Fig. 60)

Table 8 Experience from International Construction Waste Management

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