2.1 Types of construction project in construction industry

Construction industry is one of the main drivers to achieve rapid growth and development in developing country. In the field of architecture and civil engineering, “construction is a process that consists of the building or assembling of infrastructure” while construction industry means “ the construction or erection of a building or structure that is or is to be fixed to the ground and wholly or partially fabricated on site” (Construction Benefits Services, 2008). This industry’s activities include building of new structure and site preparation, maintenance, repair and improvements on the structures. There are three type of construction project in construction industry namely is construction of building, heavy and civil engineering construction and industrial construction. Heavy and civil engineering construction consists of construction of sewers, roads, highways, bridges and tunnels whereas; industrial construction consists of construction of oil industries & gas plants, chemical, power generation and manufacturing.

2.2 Type of building

There are many types of building such as;

i. Commercial building
ii. Residential building
iii. Educational building
iv. Government building
v. Industrial building
vi. Military building
vii. Parking and storage

viii. Religious building

ix. Transit station

x. Others (hospital, stadium etc)

(Source: Barrie and Paulson, 1992)

Residential and commercial types of building are most of the major type of building in every country. Besides, both type of building seen as the major project category in Malaysian construction industry (Refer Table 1.1.).

2.2.1 Commercial building

Commercial building is a type of building that will be used for commercial purposes. Among commercial building are office building, warehouse, shopping complex, restaurant, bank, hotel, convention centre, petrol station, and others. For urban area, commercial is always have combines function; such as an office on levels 2-10 with retail shop on first floor. For that reason, this commercial building is among the main type of building in urban area as it can be utilize as multipurpose buidling.

2.2.1 Residential building

Residential building is better-known as house or home. Residential construction accounts for about 30-50 percent of construction expenditures in an average year (Barrie and Paulson 1992). Residential building constitutes of:

i. Detached dwelling/ single unit housing

ii. Semi detached dwellings

iii. Attached dwellings / multi unit housing

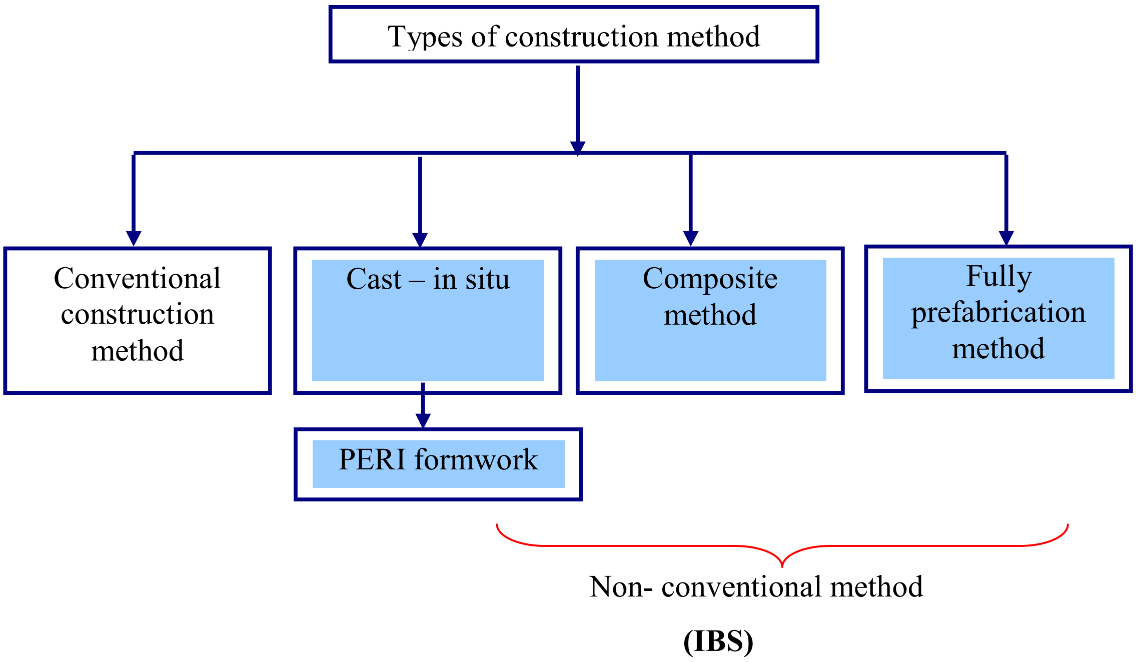
iv. Mobile dwellings

Detached dwelling is also known as single detached house. It is a free standing residential building. Among model of houses which is classified as single detached house are bungalow, villa and cottage. As for semi detached dwellings, it consists of pair of houses which are built side by side where units sharing a party wall and usually in such a way that each houses layout is a same like a twin image. Semi detached houses have front; back and any one side open spaces. Whereas attached dwellings or multi unit housing which is also known as multi-family residential apartment, condominium and flat. Finally, movable dwellings also called as mobile home. It is a prefabricated house that is manufactured off-site.

2.3 Type of construction method

There are many types of construction method for building construction. Each method applies different type of main material and activities. It is also closely related to the amount of waste generated. Each method has its advantages and disadvantages such as speed (duration of construction work) and cost.

There are four types of construction method that are usually applied by contractor which ranges from a conventional construction method to fully prefabricated construction method as shown in Figure 2.1.



(Source: Nuzul Azam Haron et al., 2005)

Figure 2.1: Types of construction method

Cast in situ, composite method and fully prefabricated method can be classified as non conventional methods and all types of industrialized building system (IBS) are categorized under one of these three method.

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2.3.1 Conventional construction method

Conventional method is one of the construction methods that have been used over the years and is popular method among contractors. This method is also known as traditional construction method which uses wooden formwork. This method uses wooden or timber formwork. In term of speed and time, conventional method takes much longer than prefabricate method and it is not environmentally friendly because normally it utilized timber as raw material where timber can only be used 2-3 times as formwork, and involves intensively huge transportation activity (Andres et al., 1998).

2.3.2 Non- conventional method (Prefabrication method)

Non conventional method is also known as IBS (Industralized Building System). IBS is also known as the complete assembly construction; a construction system where the components are manufactured at factories on or off site, transported and then assembled into a structure with minimum work (CIDB,2003). While Esa and Nuruddin (1998) stressed that IBS is a scale beginning from utilising craftsmen for every aspect of construction to a system that make use of manufacturing production in order to minimise resource wastage and enhance value for end users. Non conventional construction methods are considered not new construction method in global context but its application is still not common in Malaysia's building construction industries due to various factors such as costs, lack of skill and knowledge among workers, lack of incentive and environmental awareness and scientific information. Today with the encouragement from Malaysia's government either through encouragment or incentives, the application of prefabrication method in Malaysia's construction industry recently has been adopted by many established and well-known contractors (The Star, 2000). In the aspect of sustainable development, in order to conserve landfill capacity there is an urgent need for this industry to adopt new construction method or technologies, which can finally reduce the waste effectively (EPD, 2003).

In the countries like Hong Kong, Japan and Singapore this method is widely being used to promote the sustainable policy (Tam et al., 2005). Since 1998, Hong Kong Housing Authority had adopted and introduced many fabricated building components to their construction industry (Cheung et al., 2002). The application of facade and staircase are the common practices in their construction activities. According to Poon (2001), prefabrication method can effectively reduce waste generation in the construction process, indirectly able to improve the environmental performance for the overall site condition.

Country such as Japan, its construction industry has been focusing in adopting prefabrication as the alternative method to minimize concrete waste generation because recent waste survey in Japan shows that 85 million tons of construction waste was generated in 2000. For this figure, 42% was asphalt and concrete, 35% concrete, 9% sludge, 6% wood waste, 6% mixed waste and 2 % other waste. In term of concrete waste, this accounts for 35 million tones; 95% of which is crashed and reused as roadbed or backfilling materials. In ten years time, they believed that the amount of concrete waste is estimated 3 - 5 times higher than the year 2000.

2.3.2.1 Cast in situ

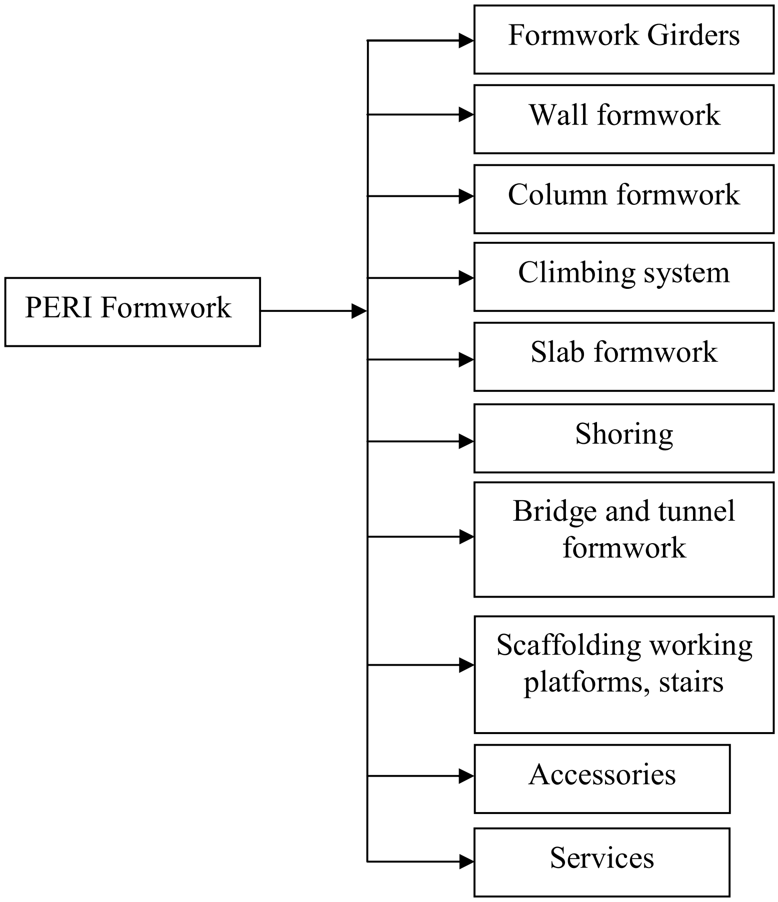
This method is very suitable for a country with limited skilled labor because there is no heavy machinery or high technology involved during construction activities. It is appropriate to almost all types of building. Its formwork is used as a mould, where wet concrete, is poured into a temporary system. The temporary system also acts as a temporary support for the structure. The objectives of in-situ method are to eliminate and to reduce the traditional site based trades like traditional timber formwork, brickwork and plastering and to reduce labor content. A carefully planned in-situ work can maximize the productivity, speed and accurateness of prefabricated construction. Cast in-situ method uses lightweight prefabricated formwork made of steel /fibreglass/ aluminium tat is easily erected and dismantled. The steel reinforcement is placed within the formwork as they are being erected and concrete is poured into the mould. When the concrete is set according to the required strength the mould is dismantled. The workers can be trained easily to erect the moulds and set the steel reinforcement. Its advantages over the traditional construction method are, its low skill requirement, can be quickly constructed, maintenance is low, structure is durable and cost can be less (Badir et al ., 1998). The example of the cast in situ formwork is PERI formwork.

PERI was founded in 1969 in Weissenhorn, near Ulm in southern Germany, and has continued to grow in size and importance year after year. PERI is an engineering business, manufacturer and service provider over 35 years; it has been recognized as the number one innovator in formwork technology with its numerous trend-setting developments and continuously improves construction in the formwork and scaffold sectors. PERI is the world's largest manufacturer and supplier of formwork systems. Extremely efficient production operations- structured according to EN ISO 9001 quality management system criteria. It is also the world's largest formwork system rental stock providing the fastest possible delivery service through its network of 65 well-organized stockyards. In many cases, renting is a better option than buying. PERI rental stockyards are in position to supply construction sites with the right materials within a very short time.

Benefits of PERI system formwork:

i. Material reuses
ii. High durability
iii. Cost savings
iv. Construction speed
v. Higher finishing quality

PERI formwork consists of many products as show in Figure 2.2



(Source: PERI handbook, 2005)

Figure 2.2: Product of PERI

Formwork girders are a central component for slab and wall formwork system and choosing the right one is crucial in achieving the highest possible level of cost-effectiveness. Formwork girders consist of two types such as GT 24 (the versatile girder) and VT 20 (the cost effective solid web girder) as shown in Figure 2.3 and Figure 2.4. While for wall formwork, VARIO GT 24 (Figure 2.5) is the common wall formwork using in Malaysia construction industry. It is the wall formwork with continuously adjustable element connections for all designs and applications. PERI VARIO is an ideal choice as project formwork, with the VARIO standard as a rentable option. Regardless whether it is industrial or housing construction, bridge abutments or retaining walls, any ground plan and all heights can be formed using PERI VARIO. For the column formwork, it is continually adjustable formwork in forming any cross-section and height. With the VARIO GT 24, square or rectangular cross-sections up to 80 x 120 cm can be concreted. PERI climbing system (Figure 2.6) is one of the common components used in Malaysian construction industry. Current project used this component is Menara Commerce project, The Troika Condominium, National Institute of Hearts, KLCC Lot 171, SMART tunnel project and Hampshire 2 condominium. There are two types of climbing system which is CB 240 and CB 160. These climbing scaffold system are framework brackets for supporting large area wall formwork. It is simple handling, fast concreting cycles and problem-free adjustment to different wall configurations. Thus valuable time-savings can be achieved.

Figure 2.3: GT 24

Figure 2.4: VT 20

Figure 2.5: VARIO GT 24

(Source: PERI handbook, 2005)

Figure 2.6: PERI climbing system

2.3.2.2 Composite method

The objectives of composite method (partially prefabricated) are to improve quality, reduce cost and shorten construction time. The concept of partial industrialized is developed from the composite nature of full industrialization and is used to describe a manufacturing or production strategy that selectively uses some industrializing aspects, while avoiding or postponing the use of others. The prefabricated construction method is combined in such a manner the features applied could be prominently demonstrated especially composing various work such as temporary facilities, building frames, building finishes and equipments (Badir et al ., 1998)

2.3.2.3 Fully prefabricated construction method

All elements in this method that can be standardized are prefabricated in the factory. Usually, this method would involve the assembly of precast elements such as floor slabs, in filled walls, bathrooms, staircase into place for incorporation into the main units, columns and beams. This method of construction has reduced the amount of site labor involved in building operations and increased the productivity of the industry. Precast building system can reduce the duration of a project if certain conditions are met (Nuzul Azam Haron et al., 2005).

Cast in-situ, composite construction method and fully prefabricated construction method are considered as non conventional construction methods which are specially aspired to increase the quality and productivity of work through the use of better technology, construction machineries, equipment and material.

2.3.3 Comparison between conventional method and prefabricate method

There are many differences between conventional method and prefabrication method in term of process and outcome. Table 2.1 shows the general comparison of conventional method and prefabricated method.

Table 2.1: Comparison of Traditional (conventional) methods and Low waste technologies (prefabricate).

Process	Traditional (conventional) methods	Low waste technologies (prefabricate)
Building Design	• Use material sizes does not correspond with the dimensions in the building	• With the standard modular approach, walls and slabs are standardized in both size an shape, being interchangeable between different building types
	• Building components not standardized	• Standardized building components
	• Down-stand beams and columns detrimental to large panel formwork system construction	• Walls and flat slabs only, no down-stand beams and columns
	• Specifications exceed the performance required	• Modification of specification to suit the contractor's available
Formwork	• Conventional timber formwork	• Large steel panel forms
	• Double the cost of using steel panel in long run	• High initial cost but balanced by the long terms savings in timber formwork
	• Labour intensive for erecting and striking formwork	• Less labour force required for erecting and striking formwork
	• Longer construction duration	• High efficiency, twice faster than timber formwork system
	• Plastering need for leveling concrete surface	• Better quality concrete products, concrete surfaces suitable for applying tiles and paints directly.
	• Reused 8-15 times, several sets of timber forms needed for high-rise block	• Reused over 100 times, one set of form sufficient to complete a block and can be reused in another sites
	• Hand lift timber board from floor to floor	• Tower crane needed for lifting formwork
	• Considerable timber waste produced	• Waste steel scrapped for recycling, less waste produced
	• In-situ placement	• Precast concrete

Concrete work	• Time consuming • Higher labour cost • Poor quality, honeycombing often occurs • Plastering required before applying tiles and paints • More waste produced	• Shorten construction time • Higher initial cost but relative cheaper for large quantity. • Mass production, high degree of quality control • Elements usually completed with necessary fixtures and finishes, no need for further finishing works • About 30% less waste than in-situ concreting
Mansonry Work	• Bricks walls or concrete block walls • Lower materials cost but higher labour cost • High skill levels • Time consuming • More waste produced • Walls with higher strength	• Internal drywall partitions • Higher material cost but lower labour cost • Easy to install, low skill lev • Four times faster than masonry work plus plastering • Wet trade not involved, hence less waste generated • Walls with lower strength
Plastering	• Conventional mortar cement • Manual applying • Suitable for rough wall surface, further leveling is required • Time consuming • Labour intensive • More waste generated	• Spray plaster • Mechanical spraying • Suitable for smooth wall surface, further leveling is not required • Faster construction • Less labour demand • Less waste generated
Hoarding	• Timber hoarding • Cheaper material cost, easy to erect • Less durable, about 2 years lifetime • Low reusability, discarded after used once • More timber waste produced	• Steel hoarding • Expensive and demand higher labour force for erection, but safe for passer-by • More durable, about 4.5 years lifetime • High reusability, waste steel scrapped for recyling • 70% less waste

(Source: Poon, 2001)

From Table 2.1, the building design process perspective, building component used in conventional method is not standardized compared to prefabrication which is standardized. As for the duration of the formwork process completion, conventional method takes longer time to complete compared to prefabrication method. The use of timber as formwork in conventional method produced high wastage production of timber. This happened due to the durability of timber that can only be reused for about 8-15 times compared to panel formwork used in prefabrication method which can be reused for about 100 times and also can be reused for other project sites. During concrete works, mansory works, plastering and hoarding process, it can be conclude that construction waste produced using conventional method has higher wastage level and took longer time to complete and need labour intensive compared to prefabrication method which produced less construction waste, took less time and less labour demand to complete the process. In order to minimize construction waste during construction activity, prefabrication method is seen one of the alternatives. Therefore, the application of prefabrication method will took less time to complete and less labor demand which is good for economy aspect.

2.3.4 Advantages and disadvantages adopting prefabrication method

However, the application of prefabrication method in construction industry also has advantage and disadvantage. A case study conducted by Vivian et al., (2009), revealed that the application of prefabrication in construction industry give benefits such as better supervision on improving the quality of prefabricated products. The author claimed that prefabrication of building components can achieve better quality product by having better supervision as the prefabricated products are tested and inspected before site installation.

Secondly, the prefabrication method can reduce overall construction cost if the standardized design layouts are used at the early stage similar to the previous projects, on the performance in cost reduction will be much better. Furthermore, the author argued besides the cost that can be saved from the early standardized design layout, project duration can also be reduced as the prefabrication can increase the productivity and efficiency of building construction.

In addition, case study by Vivian et al., (2009), proved that prefabrication method in construction tend to produce less wastage compared to conventional method in construction. According to CIDB (2009), the application of prefabrication method will increase productivity, faster completion and requiring minimal labor. Through prefabrication method, the components are prefabricated off-site. Thus, the construction site is tidier and cleaner compared to conventional method.

Even though the prefabrication method is an environmental friendly technology but Vivian et al., (2009) identified that there are several hindrances (limitation of prefabrication technology) of applying prefabrication method in construction industry such as temporary props may be required in some cases before the in-situ concrete joints required achieve strength, some cracks may develope at the joints between the precast and in-situ concrete due to temperature stresses.

In addition, in term of cost for formwork process, prefabrication method is more costly in short terms nevertheless the cost will balance by the long term saving in timber formwork. Moreover, project site adopt prefabrication method need more space to placing the prefabricated building components.

2.4 Building construction

The structure of building consists of different elements. In its turn each element is made up from any number of different components. The variety of choice, when designing elements and their components parts, gives building their individuality and character.

2.4.1 Building Elements

There are two kinds of elements:

i. Primary elements – these are the fundamental structural elements of a building.
    a. Foundations
    b. Walls
    c. Floors
    d. Roof

ii. Secondary elements – the non fundamental parts of building. They are used to improve the standards of construction, facilities and exterior of the building.
    a. Services below ground
    b. Partition walls
    c. Weathering
    d. Cladding
    e. Services

2.4.2.1 The Functions of primary elements

a. Foundations

The function of the foundation is to spread the loads imposed upon by the superstructure over an area of ground without any undue settlement occurring. There are recommendations concerning the sizes and depths of foundation.

The component parts of foundations:

- Concrete slab
- Reinforcement
- Wall up to DPC level
- Damp proof course (DPC)

b. Walls

The function of the external load bearing walls is to:

❖ Transmit the loads imposed upon them by the floors and roof to the foundations.

❖ Support any external cladding.

❖ Separate the internal environment from the external environment.

❖ Provide insulation between the internal and external environments.

The components parts of walls

- Bricks
- Blocks
- Brick ties
- Lintels
- Doors
- Windows
- Thermal insulation
- Internal wall finish

c. Floors

The function of the floors is to provide a firm and level surface on which the occupants of the building can circulate freely and easily.

The component parts of timber floors:

- Joists
- Floorboards
- Strutting
- Sound insulations
- Ceiling Material
- Electric cable
- Ceiling roses

The component parts of concrete:

Concrete Slab
Reinforcement
Floor screed
Floor tiles
Ceiling finish
Electrical cable
Ceiling roses

d. Roof

The function of the roof is to provide a weatherproof covering over all the top surfaces of the building. It also assists in the disposal of rainwater that collects on its external surfaces by directing it away from the building.

The component parts of the roof:

- Rafters
- Ridge
- Hips
- Valley rafters
- Jack rafters
- Purlin
- Roof truss
- Trussed rafter
- Thermal insulation
- Ceiling material

2.4.4.2 The functions of secondary elements

a. Services below ground

Provide a means of supplying water, electricity and possibly, gas to the building and dispose of its sewage and waste water.

The component parts of services (bellow ground):

- Drainage – Drain pipes, inspection chambers, gulleys, gratings.
- Supply - pipes, cables, stop cocks

b. Partition walls

Create divisions within the building and provide areas that are used as living spaces.

The component part of partition walls:

- Studs
- Head
- Sold piece
- Noggins
- Insulation
- wall boarding

c. Weathering

Prevent the entry of moisture and to conduct it quickly away from the building, disposing of it by way of the drainage system.

The component part of weathering:

- Gutters
- fascia brackets
- Hopper heads
- Down pipes

d. Cladding

Provide a decorative and weather proof surface over all part of the external walls of a building.

The component parts of cladding:

- Supporting framework & Fixings

e. Services

The function of the services within a building is the provision of facilities for the occupants. They should enable the occupants to exist in a comfortable, clean and hygienic environment.

The component parts of services:

- Electric supply – Electricity board meter, Cables, Sockets, Switches, Ceiling roses, light fitting.
- Water supply – Fittings, pipe clips, ball valve
- Central heating – valves, thermostat, pipes, pump, tank, radiators
- Drainage – Traps, seals, pipes
- Gas supply – gas meter, Mains stop tap, pipes, fittings, pipe clips

2.5 Building construction material

The design of a building will require many different materials to be used in its construction. The selection of suitable materials for use in the construction of the building will depend upon their fitness for purpose, cost and availability.

2.5.1 The main group of building materials

There are 17 main group of building materials:

i. *Adhesives*

An adhesives is a glue or cement that is used to stick together two or like unlike materials that have rough or smooth surfaces, with a rigid or flexible bond, either or temporarily.

Types of adhesives:

- Natural - Animal glue, casein glue
- Thermoplastic - Polyvinyl Acetate (PVA)
- Synthetic resin - Phenol formaldehyde, Urea formaldehyde
- Rubber - contact

Modern adhesives are used to bond together almost anything. They play a major part in the construction of modern buildings, sticking together many items, for example timbers, veneers, plastic laminated worktops and joint in frames.

ii. *Aggregates*

Aggregates are particle or granules of material that are used with a binder to produce a solid mass when set. By using different aggregates and binders many different kinds of material can be produced. The characteristics of the material can be altered or changed by the choice of aggregates – the cost can be reduced, the density can be altered, harder wearing surfaces can be created and different surface textures, colours and appearances can be created.

Types of aggregates:

- Binders - Bitumen, cement, plaster
- Heavy aggregates - Iron oxide, iron, steel, lead
- Lightweight aggregates - furnace clinker, foamed blast furnace slag
- Coarse aggregates - sand, gravel

iii. Bituminous products

Bituminous products are very resistant to the passage of water, very durable and easy to apply. They are usually black, brown or red in colour.

Types and uses of bituminous product:

- Bitumen - Roofing felts
- Coal Tar - Tarmacadam
- Pitch - Pitch mastic, Adhesives, paint, roofing felt

iv. Blocks

Blocks are larger than bricks and are used for walling or as filler blocks for reinforced concrete floors. They are made from clay, shale or concrete.

Types of blocks (concrete):

- Lightweight
- Dense
- Hollow
- Cellular

v. Boards, Sheet and Slabs

Boards, sheets and slabs are an essential component in the construction of modern buildings. They are available in a wide variety of shapes, sizes, thicknesses and surfaces finishes. They are easily cut, shaped and bent to cover large areas with few joints.

Types and uses:

- Plywood - Flooring, shuttering, Panelling, cupboard
- Block board - Worktops, cupboards
- Fiberboard - Insulation, ceiling, notice boards
- Plaster board - Wall cladding, ceiling cladding, fire protection

vi. Bricks

There are 3 main materials used in manufacture of bricks: clay, calcium silicate and concrete.

Types and uses of bricks:

- Common bricks - Internal walls
- Facing bricks - features, visible surface
- Engineering bricks - Structural uses, damp proof courses

vii. Cement

Cement is a mixture of clay, gypsum and either chalk of limestone. The materials are burnt in a kiln and then ground to affine powder.

Types of cement:

- Colour cement
- White cement
- Ordinary Portland cement (OPC)
- rapid hardening cement

viii. Concrete

Concrete is an artificial rock made from a mixture of coarse aggregates sand, a cement binder and water. Concrete may be used in many different ways on a project to include gigantic foundation pours and precast panels to form the building exterior. Concrete can be either cast in situ place on site or precast off site and transported to the project for installation. The main advantage of using concrete it is versatility. There are many type of concrete.

Types and uses of concrete:

- Dense - mass concrete, reinforced concrete, precast block, Concrete pipes.
- Lightweight - Precast block, internal partitions, precast slab
- Air entrained - Thermal insulation

ix. Glass

Glass is made by melting mixture of sand, soda ash, limestone and dolomite in a furnace.

Types:

- Translucent glass
- Special glass
- Transparent glass

x. Mastics

Mastics are used to seal gaps, fill cracks and act as flexible joint between different materials.

Types and uses:

- Plastics
- Elastics

} Expansion joints, sealing joints between external cladding panels, glazing, lavotary basins.

xi. Metals

Metals are mineral obtained from metallic ores that are found in the earth's crust. Metal can be worked into the required shape in a variety of ways. It can be reuse in many times (cycle) during the construction process. It can also be classified into two groups – ferrous (i.e. steel and iron) and non ferrous (i.e. lead and copper).

Types and uses of metals:

- Steel - Beams, bracket
- Copper - Pipes, cistern
- Bronze - Stopcocks, valves
- Lead - roof covering

xii. Mortars

A mortar is a layer of material more than 3mm thick use to bond together bricks, block and stones.

Types and uses of mortar:

- Cement - Work below ground level, external walls
- Lime - Internal work, work with thin join

xiii. Paints

Paint is a very thin decorative and protective coating applied to a surface in liquid or plastic foam. The type of finish required may need a number of coats of different types of paint or repeated coat of a single paint.

Types and uses of paint:

- Enamel - High gloss finish
- Gloss paint - Gloss finish
- Undercoat - Base coat for gloss
- Primer - Protective sealer for surface

xiv. Plaster

Plaster is used to provide a smooth surface coat to walls and ceiling on to which a decorative material can be applied.

xv. Plastics

Plastics can be divide into two groups – *Thermosetting* (cannot be remoulded) and *Thermoplastic* (can be reheated until they are soft and then remoulded into another shape).

xvi. Stones

Stones are using in making paving, roofing, flooring, wall cladding, internal wall lining, carvings and etc.

xvii. Timber

Timber is one of the most common materials used in the construction of building because it is so versatile. It is durable, strong yet light, easily worked and is available in a wide range of sizes, colours and textures. It is use in decorative timber, polished joinery work, veneers and general carpentry.

2.6 Construction waste

Construction & Demolition (C&D) waste defined by the Environmental Protection Department Hong Kong (2000) as ; unwanted materials generated during construction, including rejected structures and materials which have been over ordered or are over to requirements and materials which have been used and discarded.

In order to minimize construction waste, it is very important to understand and able to classify which construction waste can be reused or recycled before disposal process at landfills. The detail definitions of C&D waste and their waste classification are listed in the Table 2.2 by various authors.

Table 2.2: Definition and Classification of C&D Waste by Various Authors

Author (s)	Definition	Classification
Spivey (1974)		Classified into: ▪ Demolition materials (concrete,brick, wallboard, plaster and used lumber) ▪ Packaging materials (paper, cardboard, plastic, excelsior and metal retaining bands) ▪ Wood (trees and scrap lumber) ▪ Waste concrete and asphalt ▪ Garbage and sanitary waste ▪ Scrap metal products ▪ Rubber, plastic and glass ▪ pesticides and pesticides container
Tchobanoglous (1993)	One type of solid wastes generated within a community, which arise from construction, renovation and demolition of buildings; road repaving projects; bridge repair and clean up associated with natural disasters	CW- include dirt, stones, concrete, bricks, plaster, lumber, shingles, plumbing, heating and electrical parts. DW- similar to construction waste may include broken glass, plastic, reinforcing steel.
Gavilon and Bernold (1994)		6 categories of construction waste: 1) Design: ▪ Blueprint error ▪ Detail error ▪ Design changes 2) Procurement: ▪ shipping error ▪ Ordering error 3) Handling materials : ▪ Improper storage/deterioration ▪ Improper handling (off-site and on-site) 4) Operation: ▪ Human error (by craftsmen or other laborers) ▪ Equipment malfunctions

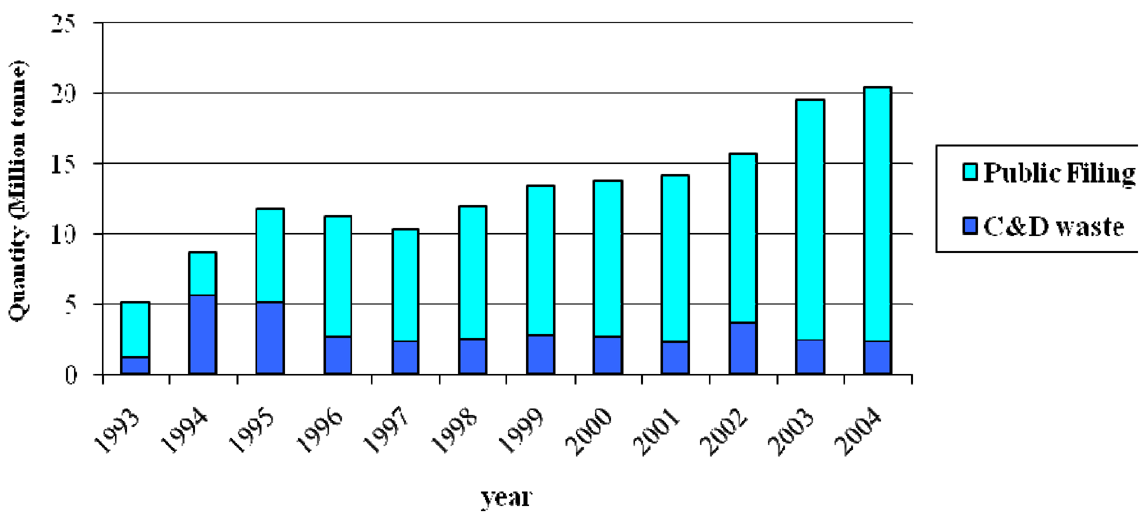
		▪ Acts of Gods (catastrophes accidents, and weather) 5) Residual: ▪ Leftover scrap ▪ Unreclaimables nonsumables 6) Others not listed
Residua (1999)	Comes from : ▪ The total or partial demolition of buildings and civil infrastructure ▪ The constructions of buildings and civil infrastructure ▪ Land leveling foundation and civil works ▪ Road construction and maintenance	▪ Concrete, bricks, tiles, ceramic and gypsum-based materials ▪ Wood ▪ Glass ▪ Plastic ▪ Asphalt, tar and tarred products ▪ Metals ▪ Soil and dredged spoil ▪ Insulation material
Lawson et al. (2001)	CW usually clean and uncontaminated while DW often dirty or contaminated and mixed	CW – mixture of unused or damaged raw materials, off-cuts and packaging. DW- includes actual building components, brick and clay, wood and material.

Note: CW –Construction waste; DW – Demolition waste

(Source: Yie, 2005)

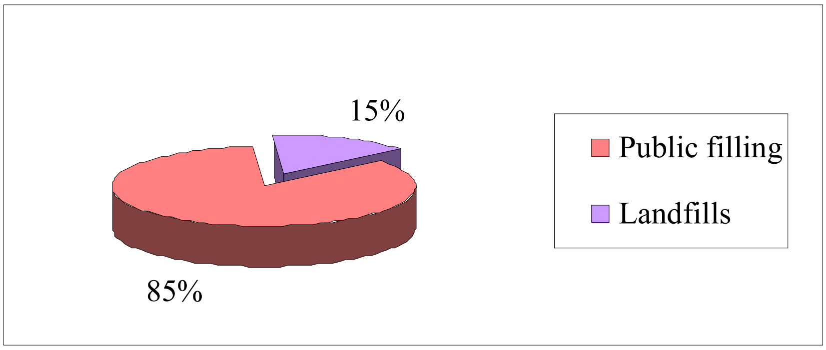
According to Poon (2004), construction waste can be defined into two types; inert and non inert waste. Useful inert waste which does not consist of active chemical content will be deposited at public filling areas as they are suitable for sea reclamation and land formation works. Some of them may be recycled to be used in construction works. Inert waste includes sand, brick, asphalt, rubble, stones, earth and concrete. However, non inert wastes were not suitable for recycling or reuse because mostly they are contaminated. For that reason, they have to be disposed to landfills. Non-inert waste includes metal, plastic, wood, paper and packaging material. Fishbein (1998), in his research found that non inert waste which is packaging material is one of the largest components of construction waste.

Whereas, Skoyles (1987) defines type of construction waste into two types which are direct and indirect material waste. Direct waste consists of complete loss of material, due to the fact that they are irreparably damaged or simply lost. By contrast, indirect waste occurs when materials are not physically lost; causing only a monetary loss for example, waste due to concrete slab thickness larger than specified by the structural design. By knowing type of construction waste, it can help contractors to reuse and recycle waste and also determine which waste will be disposed to landfills or deposited at public filling areas. According to Environmental Protection Department (EPD, 2004) in Hong Kong, the trend show that construction waste generated increasing every year (Figure 2.7) where; on average 15 % (7, 5000 tonnes per day) of construction waste material which is non inert waste was disposed to landfills while the remaining 85% (40,000 tonnes per day) inert waste disposed to public filling area from year 2000 to 2004 as shown in Figure 2.8.



(Source: EPD, 2004)

Figure 2.7: Annual generation rate of C&D materials in Hong Kong



(Source: Yeung, 2007)

Figure 2.8: Construction waste disposal in 2000-2004

2.7 Sources of construction waste

Recent research in Hong Kong found that about 5-10% of building material end up as waste on building site. The waste originated from various and many inter related sources in the whole process of implementing a construction project (Poon, 2001).

There are many contributors to this including human and mechanical factor. These are some of the causes/sources that contribute to the construction waste.

i. Damage by mishandling, weather and inadequate storage
ii. Vandalism and rework
iii. Lack of recycling
iv. Over ordering
v. Lack of storage system
vi. Poor Workmanship

Whereas according to Johnston (1981) waste on site occurs a number of reasons; which most of them can be avoid. Some of the most obvious factors are:

i. Misinterpretation of drawings
ii. Overestimating the quantity required
iii. Faulty workmanship
iv. Careless handling of material

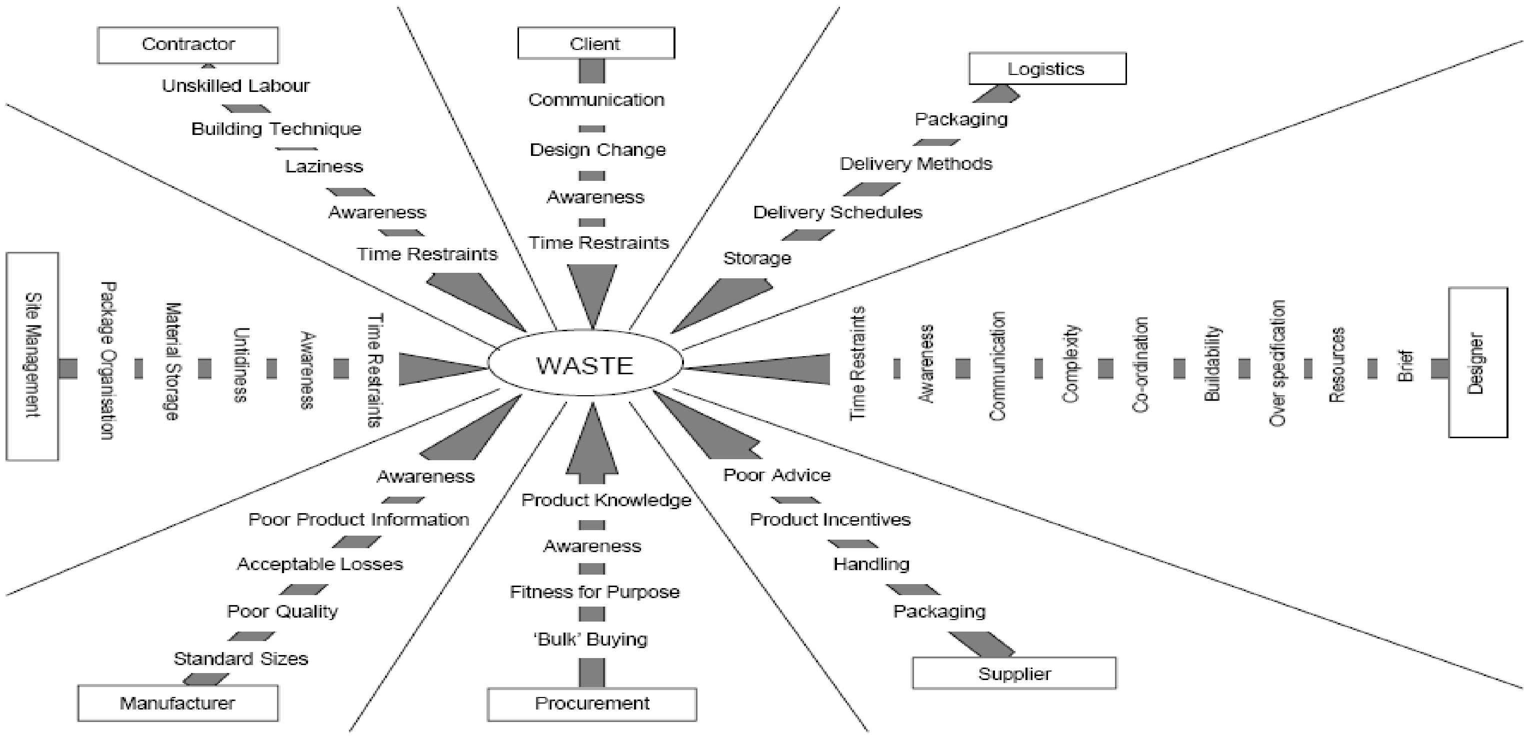
Some of the previous research classified construction waste resources into several classes. For example Poon et al (2003), mentioned construction waste resources on building site can broadly be divided into two classes: Class (1) the work processes and Class (2) poor material handling in non-working stage.

For class (1), it is not unexpected that waste can be generated from the working processes especially for those require high level of labour skill such as plastering. (Poon et al, 2003). Gavilion and Bernold (1994) found machine operation error which occurs during working process can become one of the construction waste resources on building site. For class (2), it arises from the damage and loss of material due to poor design and during transportation, storage and other material handling processes. (Poon et al., 2003).

According to Skoyles (1987), storage and handling were pointed out as major causes of waste generated. Most of the problem concerning waste on building sites are related to fault in the management system, and have very little to do with the lack of qualification of workers. Furthermore, waste is usually caused by combination of events, and not due to an isolated factor.

A similar finding was found by Poon (2004) that waste from broken raw materials like mosaic, tiles, ceramics, paints and plastering materials were produced because of careless handling and use. Gavilon and Bernold (1994) also mentioned in their research example of construction waste resources includes design error, procurement or shipping error, materials handling and residual or leftover scraps. While, Rounce (1998) pointed out that major construction waste sources are at design stage, such as design changes, the variability in the level of design details. Whereas Choo (1976), found that much of the materials wastes are related to improper design.

Craven et al. (1994) and Gavilon and Bernold (1994), categorized and classified construction waste resources into six groups which are design, materials procurement, materials handling, operations and residual related.Keys et al (2007), summarized the sources of construction waste generated by many aspects as shown in Figure 2.9. The author found there are many parties and aspects contributed to the generation of construction waste such as designer, supplier, contractor, manufacturer, logistic, client, site management and procurement. Even though the origin of waste is different, however there will be two main aspects in each source of waste which are time restraints and awareness. Whereas, according to Johnston, (1981), construction waste is not an easy thing to classify but the factors to highlight is source of construction waste on site is occurred by human and technical error.



(Source: Keys et al., 2007)

Figure 2.9: Sources of construction waste generated by many aspects

2.7.1 Construction Waste handling

Much of the problem basically from the inherent sense of speed in construction operations, but essentially the fault lies within insufficient supervision and careless attitude, together with misplaced incentives. Construction material namely concrete, timber and metals (steel) are the main fundamental materials essential in implementing construction activities. Those material were mainly used during the same stages of work namely structure and brickwork. The quantity of those material also are usually requires in a large amount compared to others construction material. While they are major components of materials that are required in every construction projects, they are also among the major material that tends to have high or percentage of wastage because of many factors such as during handling material process. It was proved by several researchers (Poon et al, 2004; Bergsdal et al, 2007; Gheewala et al, 2009) which are focused only on major type of C&D waste with significant amount explicitly as concrete, timber, steel and bricks.

2.7.1.1 Concrete waste

Concrete is used in large quantities, particularly for foundation work and ground floor slabs. Due to the uncertainty material consumption, it is often wasted because the site managers often order an additional quantities required in order to avoid interruptions in the concrete-pouring process (Carlos et al., 2002). In addition, an excessive dimension of concrete dimension piles and curtain walls also caused unexpected waste. This problem was mainly related to the lack of precision in excavation methods. Weathers changes and meal breaks do affect the rate of construction progress due to the delayed work (Johnston, 1981).

2.7.1.2 Timber waste

Timber waste from construction and demolition works is produced in large quantity all over the world (The Constructor, 2010). Based on Queensland Government Environmental Protection Agency (2002), the major source of timber waste during construction is from the off-cuts formwork, off-cuts from the internal fit-out and the packaging materials. Other than that, timber can be reuse only several time according to the quality. Due to that, timber becomes one of the major material wastes generated in construction process. This is proved by Lauer (1993); in a case study at Minnesota is as shown in Table 2.3.

2.7.1.3 Steel reinforcement waste

Steel reinforcement is hard to handle due to its weight and shape. A study conducted by Carlos et al., (2002) found that there are three main reasons that can be pointed out for steel reinforcement wastes which are; some steel bars may have an excessively large diameter due to fabrication problems; some short unusable pieces are produced when bars are cut and trespassing.

2.7.1.4 Bricks waste

Damaged of brick is caused by many factors. Carlos et al., (2002) found that delivering process, poor handling and unloading operations were the major source for bricks. While according to Johnston (1981), forklift equipment which is handling by the unskilled drivers is one of the sources of brick waste.

Usually the drivers will make several cracks before inserting the tines into the apertures, damaging the facing in that area of brick pack. Unnecessary jolting by the forklift as the packs are moved can also damage the brick. However, loose bricks are indiscriminately used for many purposes on site, for example as a base to support other materials or as packing for platforms and walkways, while occasionally they are even used as ballast to remove vehicles from muddy sector of the site. They are also used as substitute formwork during concrete operations, particularly where steps are formed in foundations and substructure work.

2.8 Factors that influence construction waste composition

Construction wastes are categorized in a variety of ways, and each category produces wastes with different composition and characteristics. For example, road construction waste differs from bridge waste, which differs from building waste. Whereas road construction waste generates large quantities of just a few different waste items (mainly asphalt and concrete), building construction waste generates many different waste items in smaller amounts (with wood as the largest single item).

Within the category of building construction waste, the size and type of the building (e.g., an apartment building versus a single-family house) affects the composition of the waste. Even for one building type (e.g., a single-family house), the waste generated depends on the activity conducted (i.e., new construction, renovation, or demolition). For example, construction generally produces "clean," unaltered, and separate waste items (e.g., unpainted wood, new concrete) (MVC, 1992).

Research by Hong Kong Polytechnic University (2001) indicated that there are three main factors affected the characteristic of construction waste.

i. Structure type (e.g., residential, commercial, or industrial building, road, bridge);
ii. Structure size (e.g., low-rise, high-rise)
iii. Activity being performed (e.g., construction, renovation, repair, demolition)

Additional factors that influence the type and quantity of C&D waste produced include:

a) Size of the project as a whole (e.g., custom-built residence versus tract housing);
b) Location of the project (e.g., waterfront versus inland, rural versus urban);
c) Materials used in construction (e.g., brick versus wood);
d) Demolition practices (e.g., manual versus mechanical);
e) Schedule (e.g., rushed versus paced)
f) Contractors' "housekeeping" practices

A similar finding by Begum et al., (2006), found that the construction industry is responsible for producing a whole variety of waste, the amount and type of which depends on factors, such as stage construction, types of construction work and practices on site.

Table 2.3 shows, a study conducted in Minnesota in which 1993 proved that a type of building is one of the factors that contributed to the amount of waste generated.

Table 2.3: Composition of Construction Waste By Construction Type In The Twin City In Minnesota (By Volume**).**

Waste Type	Residential Construction	Commercial construction
Wood	20-35%	20-30%
Crates & pallets	--	1-5%
Cardboard	5-15%	5-10%
Paper packaging	<1%	~3%
Concrete & block	1-8%	10-20%
Brick	--	1-5%
Drywall	10-20%	5-10%
Electrical wire	<1%	~2%
Shingles	1-8%	--
Fiberboard	1-8%	--
Steel	<1%	1-8%
Plastics sheeting and bags	<1%	~3%
Polystyrene insulation	--	~3%
Overspray from fireproofing products	--	0-5%

(Source : Lauer, 1993)

While a study has been done in the United States on estimation composition of construction debris (Table 2.4), the result revealed that timber formwork and concrete waste were the highest composition generated in the United States compared to other material.

Table 2.4: Estimated composition of C&D debris in United States.

Material	Composition (%)
Steel and iron	2.73
Copper	0.02
Lead	0.06
Aluminum	Negligible
Concrete	53.75
Brick	21.21
Timber (wood)	22.01
Glass	0.22
Plastic	Negligible
Total	**100.00**

(Source: Roundtable Dialogue, 2002

2.9 Storage of materials

Storage is an important aspect. It is not only the place to keep the material under proper condition but it also the place where to ensure that stocks are always available on site to meet requirements to avoid delays to the contract. Storage under proper conditions includes stacking the materials in racks and frames, retaining them in bins and boxes, protecting them from impact damage and enclosing them adverse weather conditions.

Storage actually consists of more than one operation and involves:

i. Delivery of goods to the site
ii. Offloading
iii. Stacking
iv. Protection against deterioration
v. Identification for future reference
vi. Accounting procedures
vii. Issue of materials to operative for use on site
viii. Loading for transfer to construction areas
ix. General movement of goods

(Source: Johnston, 1981)

Practicing the good storage can help in reducing the amount of wastage and help the contractors keep to allowable wastages percentages. Every material has specific storage method. According to Poon (2001), in Table 2.5, these materials usually will be stored either under cover, secure area, on pallets or material bound. High cost material such as wood, metal, internal fitting, cladding, glass, paint, clay, ironmongery and oils were stored in secure area and under cover to protect from damage and theft. Whereas some of the material will be stored in original packaging until required to avoid the material damaged.

Table 2.5: Raw material storage

Materials	Store under cover	Store in secure area	Store on pallets	Store material bound	Special Requirements
Sand, gravel, rock, crushed concrete					Store on hard standing base to reduce wastage. Store in bays if large quantities
Plaster, cement	√		√		Avoid material getting damp
Concrete, paviors					Store material in original packaging until used, and protect from vehicle movements
Clay pipes, concrete pipes			√	√	Use stoppers and spacers to prevent rolling and store in original packaging until used
wood	√	√		√	Protect all types of wood from rain
metals	√	√		√	Store in original packaging until used
Internal fittings	√	√			Store in original packaging until used
cladding	√	√			Wrap in polythene to prevent scratches
Sheet glass, glazing unit		√	√		Protect glass from breakage due to bad handing or vehicle movements.
paints		√			Protect from theft
Bituminous felt	√	√			Store in rolls and protect with polythene
Insulting material	√	√			Store under polythene
Ceramics tiles	√	√		√	Store in original packaging until required
Glass fiber	√			√	
ironmongery	√	√			
oils		√			Store in bowers, tanks or cans according to quantity-protect container from damage to reduce likelihood of spillage-use a bund
curbstones				√	Protect from vehicle movements & tar spraying to reduce damage
Clay & slate tiles		√	√	√	Keep in original packaging until used
Topsoil, subsoil					Store on hard standing base to reduce wastage and keep segregated from potential contaminants
Precast concrete units					Store in original packaging, away from vehicular movements.

(Source: Poon, 2001)

2.10 Waste quantification

Waste quantification is one of the main parts needed in implementing waste minimization and also important towards environmental issues. With knowledge of waste quantification, construction company can choose the best construction method in order to save their cost for debris disposal and produce less construction waste on site. Besides, the waste quantification process also can determine which construction activity generates more construction waste. However, in order to develop a waste quantification calculation, process of record keeping indeed is essential and lack of the needed data will affect the whole waste quantification process. Hence, waste quantification is about record keeping process as it depends on the available data. There is few waste quantification calculation that have been developed from previous study by various researchers.

In Hong Kong, Poon et al., (2001), developed the formula of *waste index* and *wastage level*. Waste index is a calculation to estimate the amount (volume in m^3) of waste generated (debris) per m^2 of Gross Floor Area (GFA) for building projects. Waste index equation is as follows :

(W) = total waste generated by the project (m^3)
(C)= Waste index = (W) / GFA
i.e 1m^2 area of GFA generates (C) m^3 of waste

According to Poon et al (2001), the generation rate of construction waste index in Hong Kong is as shown in Table 2.6. Hong Kong construction industry uses the waste index generation rate as a construction activities standard.

Table 2.6: Waste index for various types of projects in Hong Kong

Project	Waste index
Public residential	0.175 m^3 / m^2 GFA
Private residential	0.250 m^3 / m^2 GFA
Commercial office	0.200m^3 / m^2 GFA

(Source : Poon et al., 2001)

Waste index calculation can assist the construction company to estimate the overall construction waste (debris) generated per GFA in order to save their cost of debris disposal transportation and to develop good planning on resources and environmental management. *Wastage level* is a calculation of construction materials end up as waste by calculating the actual quantity of materials ordered and the quantity of materials that had been utilized or used.

On another study in Greece by Fatta et al., (2003), waste quantification formula was developed using some representative estimation for the waste generation rate and density of waste that represent the characteristic of national waste generation based on average value from the National Statistical Services of Greece (NSSG). The equations is as follows:

$$CW = [NC + EX] \times VD \times D$$

Where;

CW = construction waste in tons,

NC = new construction in m2 (from NSSG),

EX = extension infrastructure in m (from NSSG),

VW = volume of generated waste per 100m2 = 6m3/1000m2 (national average),

D = Density of waste = 1.6 ton/m3 (national average)

DW = ND x NF x SD x WD x D

Where;

DW = demolition waste in tons,

ND = no of demolition (from NSSG),

NF = mean value of no of floors that building has = 1.3

SD = surface of each building demolished = 130m2 (national average),

WD = generation rate of each demolition = 0.8m3/m2 (national average),

D = density of waste = 1.6 tons/m3 (national average)

Moreover in Thailand, Gheewala et al., (2009) also developed the formula/ calculation of waste quantification using the average waste generation rate from HQ Air Force centre for Environmental Excellence. The average waste rate for new residential and non-residential project is 21.38kg/m2 (0.2138 m^3 / m^2 GFA) and 18.99kg/m2 (0.1899 m^3 / m^2 GFA) respectively. The calculation of wastage level conducted by Ghewala in Thailand is based on different type of building. The equations is as follows:

Qx = A x Gav x Px

where ;

Qx = quantity in tons;

A = area of activity in m2,

Gav = waste generation rate,

Px= percentage of waste material

From the review of previous formula/ calculation, it can be concluded that, there are two level of waste quantification calculation/formula either for national level (general estimation such as Fatta et al., 2003 and Gheewala et al., 2009) or project level (Poon et al., 2001). However both levels of construction waste quantification still need data on the waste volume and waste characteristic. Therefore, there is a need to implement and record the quantitative data on construction site.

2.11 Construction and demolition waste management in some selected Asian Countries

Nowadays, countries in Asia have their own definition of construction and demolition waste. The Reduce, Reuse and Recycle (3R) concept have already been used widely and practiced in most C&D waste management in some Asian countries such as Japan, Hong Kong Special Administrative region (SAR), India, Sri Lanka, Singapore others. The summary of C&D waste management in some selected Asian countries is as shown in Table 2.7.

Table 2.7: Summary of C&D waste management in some selected Asian Countries

Country	Annual C&D waste (amount or proportion of the total waste)	Strategies and Technologies	Practices	Policy and institutions
Singapore	200,000 tons	Recycling of construction waste into aggregates	Reduce, reuse and recycling	Building and Construction Authority (BCA) established an ISO 14000 Certification Scheme- a surveillance audit for construction firms
Taiwan	Approximately 2.4 million metric of concrete waste	Recycling Technology (Recycled concrete and aggregate)	Recycled concrete aggregate and recycled aggregate	-EPA initiated has been practiced -Development of Construction Waste Management Centre
Vietnam	Construction waste and sewage sludge make up for about 8% of municipal waste	Reuse	Construction waste is normally used for back (public) filling	-

Thailand	NA	Portion of C&D waste disposed to landfills	Reduce, reuse and recycling	-Development of Construction and demolition waste program -Investigation on recycling and reuse of Debris from the Tsunami Disaster
Malaysia	28.34% (including industrial waste)	Reuse and recycling	Reuse and recycling	Reuse and recycling has been practiced
Sri Lanka	NA	Reuse and recycling such as door frames	Reuse and recycling industry	-Reuse and recycling has been practiced -Development of Construction Waste Management Centre
India	14.5 metric ton	Recycling and reuse & Recycling and reuse of marble waste in building application	Portion of C&D waste is recycle and reuse in building materials and share of recycled materials	-Ministry of Environment and forests has mandated -Environmental clearance for all large construction projects
Hong Kong SAR	42%	Reuse – done by selective demolition technique	Reuse of C&D waste in grade 37% - 80% public filling areas for land reclamation purposes for period 12 years	-Construction Waste Disposal Charging Scheme -Public Works Programs, the contractors are required to formulate waste management plans -Adopt low waste construction technique
China	28.34% (including industrial waste)	Reuse and recycling	Reuse and recycling	Reuse and recycling has been practiced

(Source: Nitivattananon et al., 2007)

From the Table 2.7, it can be concluded that most of Asia countries except Thailand are practicing recycling and reuse activity in construction waste management. However, currently existence of regional and national policies, laws and regulations governing 3R principles for C&D waste still minimal in Asia. Some of the policies exist and others are still in the process of formulation. Most of the countries such as China, India, Sri Lanka, Thailand and Vietnam do not have specific regulations designed for C&D waste, although some countries include some sections for construction waste in their solid waste management regulations. Therefore with the current situation in Asia countries, Nitivattananon et al., (2007) stressed out that stakeholder participation, policy formulation and efficient implementation of C&D waste management and capacity building should be taken into consideration in the Asian countries.