4 MINIMISING AND MANAGING BUILDING WASTE – LOW WASTE BUILDING TECHNOLOGIES

4.1 Current State of Building Technology

The construction industry in Hong Kong has been relying heavily on traditional building technology. Buildings are usually constructed by the conventional cast-in situ method with the use of bamboo scaffolding. The construction processes are labour intensive and inevitably the quality of the work depends on the skill of the workers. The common use of sub-contractors makes management control even more difficult and few measures have been introduced to control the generation of waste on construction sites. The contractors, particularly the smaller ones, do not have sufficient capital for investment in advanced building technologies.

Recent research indicates that time and cost are the most important factors considered by contractors in the selection of construction methods or technologies for building projects. The reduction of C&D waste is the least important factor in the minds of the contractors. This can be attributed to the availability of relatively inexpensive (currently free) means of waste disposal and the generally low environmental awareness of the construction industry in Hong Kong.

Figure 4.1 Timber Waste

Figure 4.2 Concrete Waste

4.2 Major Waste Producing Processes On Building Sites

Figure 4.3 shows the ranking of the major waste producing construction activities reported by the respondents to a questionnaire survey conducted by the Hong Kong Polytechnic University in 1999.

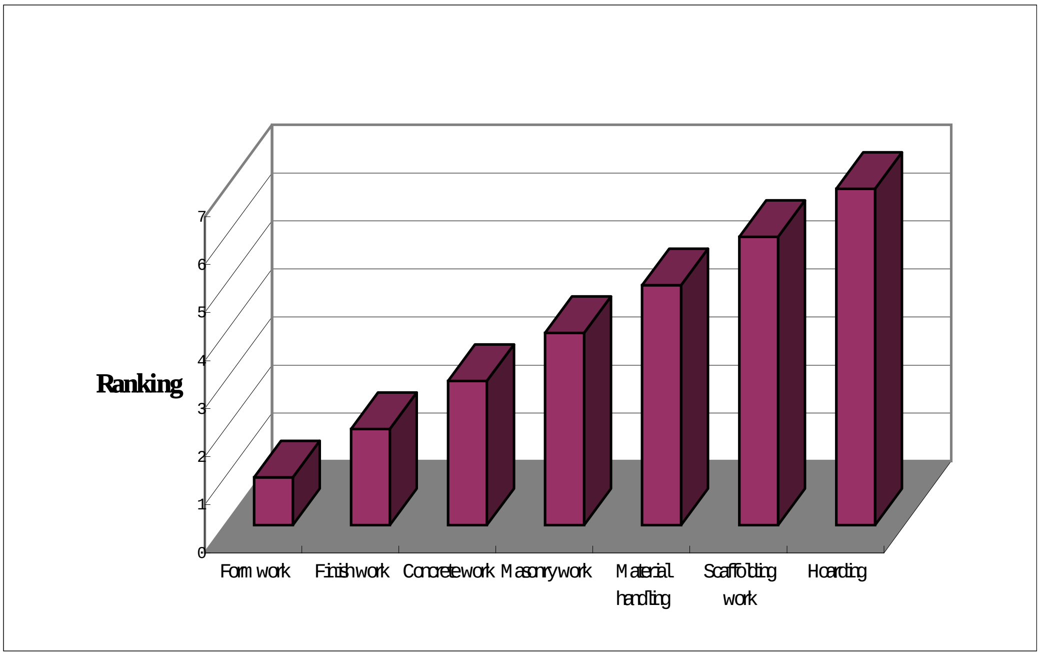

Figure 4.3 Ranking of Major Waste Producing Processes On Building Sites (1 – Most waste, 7 – Least Waste)

It is revealed that the types of construction operations are closely related to the amount of waste generated. As depicted in Figure 4.3, timber fomwork is the major contributor to construction waste. The wet trades of finishing work such as screeding, plastering and tile laying are identified as the second major set of waste generation processes in the construction of buildings. Concrete work and masonry work were the next significant groups.

4.3 Low-waste Building Technologies

Available, however, are low-waste building technologies which can reduce waste generation in the construction processes as follows:

4.3.1 Precast concrete elements

Precast concrete element systems can be used for floor slabs, façades, external elements such as bay windows, staircases and internal partition walls. Take a façade for an example. The mould is carefully engineered to the required profile and dimensions and is made of steel instead of timber. Unlike timber formwork, it can be reused very many times with minimal distortion or damage. Locations for boxing-out, conduits, window frames and reinforcement are precisely marked and fixed into position. Once all the preceding operations are completed and inspected, the concrete is poured, compacted and finished, and the curing of concrete proceeds in a controlled environment. At a predetermined time after casting the façade will be demoulded and set aside mechanically for subsequent dressing of the unit such as with tiling.

Figure 4.4 Precast façade

Figure 4.5 Precast staircase

As the façade is cast to the designed profile and dimensions the layout of tiles can be planned in such a way that only minimal cutting of tiles is required. Tiling can be carried out at ground level in the prefabrication yard where a safe and comfortable working environment prevails. For tiling insitu, the workers otherwise need to work outdoors on bamboo scaffolding hanging at high levels. Good quality of tiling work can be much better provided and maintained by a small group of experienced and skillful plasterers under factory conditions where properly run quality assurance procedures can also be more easily applied.

Upon delivery to the site, the precast façade will be lifted by crane to the designed position, secured with temporary bracing and fixed into position by non-shrinkage grout. Part of the concrete slab adjacent to the façade is left unbuilt until the façade is fixed in position after which this part is concreted to form a homogenous tie between horizontal and vertical planes.

Precast elements may be made in a casting yard on site. It is believed that precast concrete construction is about 25% more productive than the conventional method of construction. Additionally, because of mass production, the materials can be better utilized and wastage can be kept to a minimum. The use of formwork can also be reduced by the use of precast concrete units.

Figure 4.6   Prefabrication yard on site

Figure 4.7 Transfer of prefabricated façade to the working level

Figure 4.8   The precast façade is secured with temporary bracing

However, there are some limitations in using precast concrete. If precast units are only small in quantity, the construction cost will be high. In addition, storage and transportation of precast units can also be a problem for construction sites located in congested urban areas.

4.3.1.1 Semi-precast slab

A slab is called semi-precast when only the lower portion of the floor slab is prefabricated at the factory. It is then hoisted and set into position on site and acts also as shuttering to receive the top layer of floor slab which is cast insitu. The whole slab is a permanent composite of precast and insitu concrete. As for precast façades, boxing-outs are cast at the designed locations during slab fabrication at the factory. The subsequent services installation also becomes more efficient.

Figure 4.9 The lower layer of semi-precast slab

4.3.1.2 Precast cladding

Precast cladding is a new construction method for tiling works. The cladding panels are manufactured in the precast factory. The production processes are: place wall tiles onto the steel mould face down, pour lightweight concrete onto the back of the tiles, and demould after hardening The tiles are thus cast integrably with the lightweight concrete and no traditional tile fixing by cement mortar or adhesive is required.

At the construction site, the positions for holding brackets will be set out, and cladding panels leveled and fixed. Figure 4.10 shows the fixing of the cladding panels.

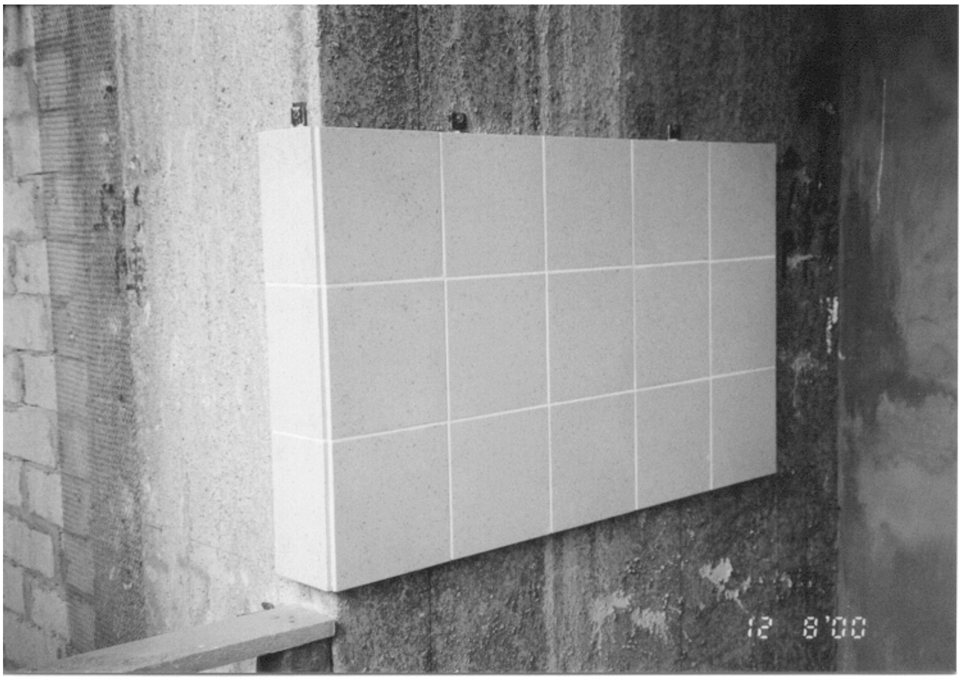

Figure 4.10 Fixing of cladding panel by brackets

The advantages of the cladding panels are:

- Reduced quantity of skilled labour
- Less wastage – wet trades on site such as plastering and tiling are eliminated
- Less waste produced
- Better quality
- Flexible time control – no setting and curing time are needed on site
- A clean and safe working environment is achieved

4.3.2 Large panel formwork

Large panel formwork consists mainly of large pieces of metal formwork. It is most suitable for construction activities where formwork is highly repetitive as it can be reused many times. Therefore, its design is specified for the construction of the load bearing walls of typical floors in high rise tower blocks.

Compared with traditional timber formwork, metal panel formwork has several advantages. The use of large panel formwork can save time and labour in erecting, striking and re-erecting the formwork as the panel is handled as one unit. It can also produce a concrete surface, which is neater than is produced normally by conventional timber formwork, and the surface essentially needs no additional applied finishes for levelling. On site waste audit records also show large panel formwork systems are effective in reducing concrete waste generated by losses due to damaged formwork, which usually accounts for 30% of the total concrete waste. However, because of the weight of large panel formwork, tower cranes should be available for its handling.

Different large panel formwork systems are widely used today by contractors for constructing standardised housing blocks, and are broadly classified as wall forms, table forms and tunnel forms.

- **Wall Forms**: The wall forms are combined with the slab form so that the wall and slabs can be formed monolithically in one casting operation, and the number of joints between panels is minimised. There is less chance of grout leakage or an uneven surface finish at the joint, which is a common fault with in traditional timber formwork.

- **Table Forms**: Standard modules of housing blocks are relatively large in span and large table forms are widely used for assembly time reduction, fewer joints and better surface finishes. The table method uses separate vertical forms for walls and horizontal table forms for floor slabs. The work is done in two stages. First, the walls are cast, and forms are stripped, the tables are then positioned, and the horizontal slabs are cast.

- **Tunnel Forms**: The half tunnel is composed of vertical and horizontal panels set at right angles and supported by struts and props. The walls and slabs are cast in a single operation. Like the wall-forms and table forms, this reduces not only the number of joints, but also the assembly time. Therefore, the casting of walls and slabs can be completed in the one day.

4.3.3 Alternative formwork materials

4.3.3.1 Steel forms

Because steel forms are very durable, one set of steel forms can be used to complete a project, and then reused for another project or scrapped for recycling. Steel forms can produce a better quality concrete finish when compared with timber forms. Although their initial cost is higher, they can be cheaper in the long run, particularly with their recycling potential.

Figure 4.11 Large panel formwork

Figure 4.12 Removal of formwork

4.3.3.2 Composite steel decking

Steel decking, becoming a permanent part of a composite slab, serves as both the working platform and formwork for supporting the insitu slab concrete in the construction stage. The steel of the decking can also utilised to provide some of the required permanent reinforcement for the slab. In other words, the decking can replace both timber formwork and bottom reinforcement, reducing the amount of temporary works and formwork required.

4.3.3.3 Aluminum forms

Aluminum formwork consists of small aluminum framed panels which are easy for handling. It is fast to erect and strike and the floor cycle can be 4 days. It is durable and can be reused over 100 times. Although it is more expensive than steel and timber, its merit is its lightweight and recycling potential.

Figure 4.13 Installation of aluminum formwork

4.3.3.4 Plastic forms

PVC and polyurethane forms can be used to replace timber forms in either rigid or flexible formats. Special floor forms made of fibreglass are occasionally used (6%). They can be reused over 50 times and produce a concrete surface finish similar in appearance to fine snake skin. If a smooth finish is desired, a paste wax or water-based release agent can be applied to the form.

- *Rib Loc circular column*: This UPVC form is usually used to cast circular columns of diameter ranging from 150 to 3000mm. It is made by spirally winding a ribbed plastic profile into a tube. This enables column forms to be constructed which are strong, lightweight, easy to strip and which provide an excellent surface finish. The surface also incorporates the inherent "waxiness" of extruded plastic and no form oil is required. Square stabilisation timbers are fixed at the foot of the column formwork to stop the formwork moving out of position. Vertical bracing timbers are placed against possible movement while concreting. The process is cost efficient with recycling potential.

Figure 4.14 UPVC column forms

Figure 4.15 Erection of column forms

- *Pecaform* : This is made by laminating a layer of polyethylene to each side of a high tensile steel wire mesh. This combination creates a material that is both light and structurally strong, making it very easy to handle. It can be used for constructing ground beams, pile caps, footings, curved structures, ribbed and waffle slabs. The formwork is cut-to-size and bent to shape at factory and arrives at site ready for installation. There is no need to strip formwork after the concrete has cured. No waste is produced. A clean and neat site can be obtained in the foundation stage with Pecaform.

Figure 4.16 Construction of pile caps using Pecaform

Figure 4.17 Backfill around pile caps about 150mm from the top level of Pecaform

4.3.3.5 High Density Overlaid (HDO) Plywood

The coating of conventional plywood with a thick layer of polymer resin may improve the quality and durability of the formwork. For example, applying a medium density overlay or a high density overlay on plywood can increase the number of reuses to 20. The form can be easily dismantled and handled by small cranes and can be adjusted to suit architectural requirements.

4.3.4 Drywall

Figure 4.18 Dry Wall

Drywall is a kind of factory made wall panel. It replaces the traditional brick and block dividing wall in buildings. It involves less labour and skill requirement, and provides a shorter construction time, better product quality and higher flexibility for future layout changes. A comparison of the two construction methods is given in Table 4.1. Full height panels are assembled and conduits can be easily installed through its preformed tubular spaces with minimal cutting, jointing and patching up. Its lightweight characteristic, at about half the weight of solid concrete block reduces the dead load imposed on the building structure. The surface of the wall panel can be easily finished with a thin coat of skim plaster in lieu of the thick cement sand plaster in traditional block wall. Much less wet trade work is involved in the assembly process and less construction waste is generated at the end.

	Precast Partitions	**Brick walls/block walls**
Cost	initial cost is higher, but saving in plastering, construction time and labour cost	lower initial cost, but higher labour cost
Weight	3 to 4 times lighter than brick walls	heavier loads on structural frames and foundations
Speed of erection	four times faster than brick walls	time-consuming
Plastering	only thin plaster (10mm) is needed	require thick plastering to obtain smooth surface
Wet trades	not necessary	Necessary

Fire resistance	2 times better than brick walls	Poorer
Thermal Insulation	about 5 times better than brick walls	Poorer
Sound Insulation	Similar	Similar
Mechanical strength	much lower	8-9 times higher than drywalls

Table 4.1 Comparison of precast partitions and Brick walls/Block walls

4.3.4.1 Dry wall plus infill

In order to provide the solid feel and sense of security traditionally associated with masonry walls, dry wall plus infill can be adopted. For example, the "Hardiwall" Solid Wall System is an internal non-load bearing wall comprising light gauge galvanised steel stud framing, lined with fibre cement sheets and filled with a proprietary lightweight concrete core mix. It reduces structural design requirements due to lighter weight wall construction. Increased floor space can be achieved due to thinner walls. It is up to 3 times faster to install than a masonry wall. No wet trades are involved, which eliminates site mess on each floor, reduces site waste, and therefore waste removal and dumping costs. It provides a very smooth flat finish and eliminates the need for plastering to finish the wall surface. The cost is about HK$300 to 340 per square metre, ready for painting which includes material and labour, at July 2000 prices.

4.3.5 Machine sprayed plaster

Machine sprayed plaster was originally used in civil engineering application, but now replaces traditional cement mortar in some building projects. The major difference between the mechanized plaster and the traditional cement mortar is that the former is mixed and applied mechanically whilst the latter is applied and trowelled smooth by hand. The use of machanised spraying has the merits of high productivity, low labour demand and less waste. The cost of the spray plaster material is HK27 per square metre and the labour cost is HK$53 per square metre, as at December 1999 prices.

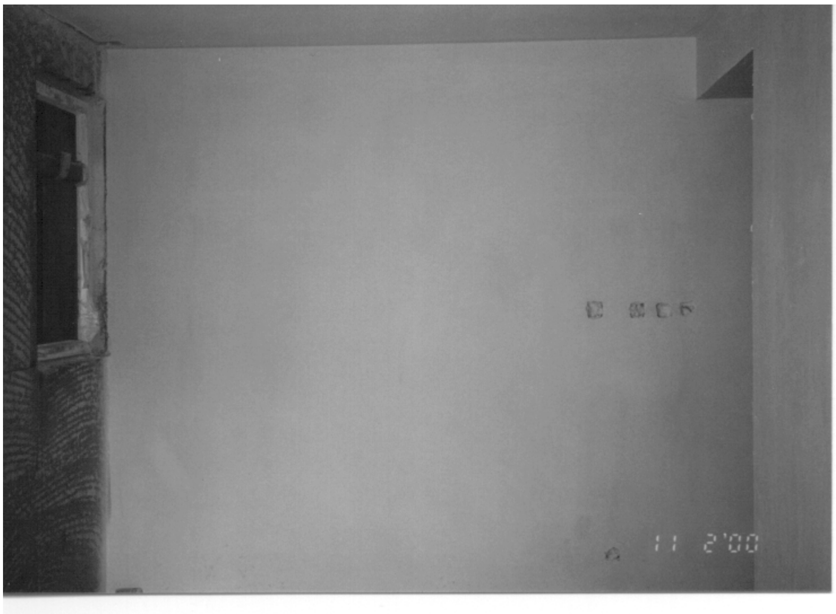

Figure 4.19 A wall finished by spray plastering

4.3.6 Other waste minimisation examples

Using factory made steel fabric as reinforcement for slabs and walls, steel hoardings for longer life span (see figure 4.20), hanging cradles as working platform for exterior wall finishing work, and steel scaffolding for higher durability would all also reduce waste generation.

In addition to prefabricated joinery in kitchens, prefabricated bathrooms (see figure 4.21), and proprietary doorsets are initiatives of the Housing Authority intended to reduce construction waste and other costs.

Figure 4.20 Steel hoarding

Figure 4.21 Prefabricated bathroom

4.3.6.1 Metal-Bamboo Matrix System Scaffold

In Hong Kong, bamboo scaffolding has been the mainstream in the past. However, due to the poor and inconsistent quality of bamboo itself, reports of bamboo scaffolding related accidents are increasing. A vendor, therefore, has designed a new scaffolding system – the ‘Metal-Bamboo Matrix system Scaffold’(MBMSS).

The principal of MBMSS is to combine the good characteristics of metal scaffolding and bamboo scaffolding. It comprises steel pipes (60%) and bamboo poles (40%). The steel pipes are used as main poles and ledgers for supporting the loading, and provides more stable, secure and reliable scaffolding than pure bamboo scaffolding. The bamboo poles in MBMSS reduce the total weight of scaffolding and increase its flexibility. MBMSS enables flexibility and adaptability to the various miscellaneous and different requirements which occur in practice, providing a higher productivity and efficiency than metal system scaffolding.

Metal-Bamboo Matrix System Scaffold is composed of two layers (Figure 4.22) as for traditional metal or bamboo scaffolding. For the outer layer, metal tubes are used as the main posts and main ledgers while bamboo is used as guardrail and fencing. For the other members, bamboo is used to minimize the loading.

Together with other components, such as catwalks, toeboards and staircases, MBMSS provides a stable and safe working environment and access for work. The catwalks are made of aluminum while the toeboards are made of plastic. These materials can be reused and help to save timber waste.

MBMSS is about 15% more expensive than traditional bamboo scaffolding.

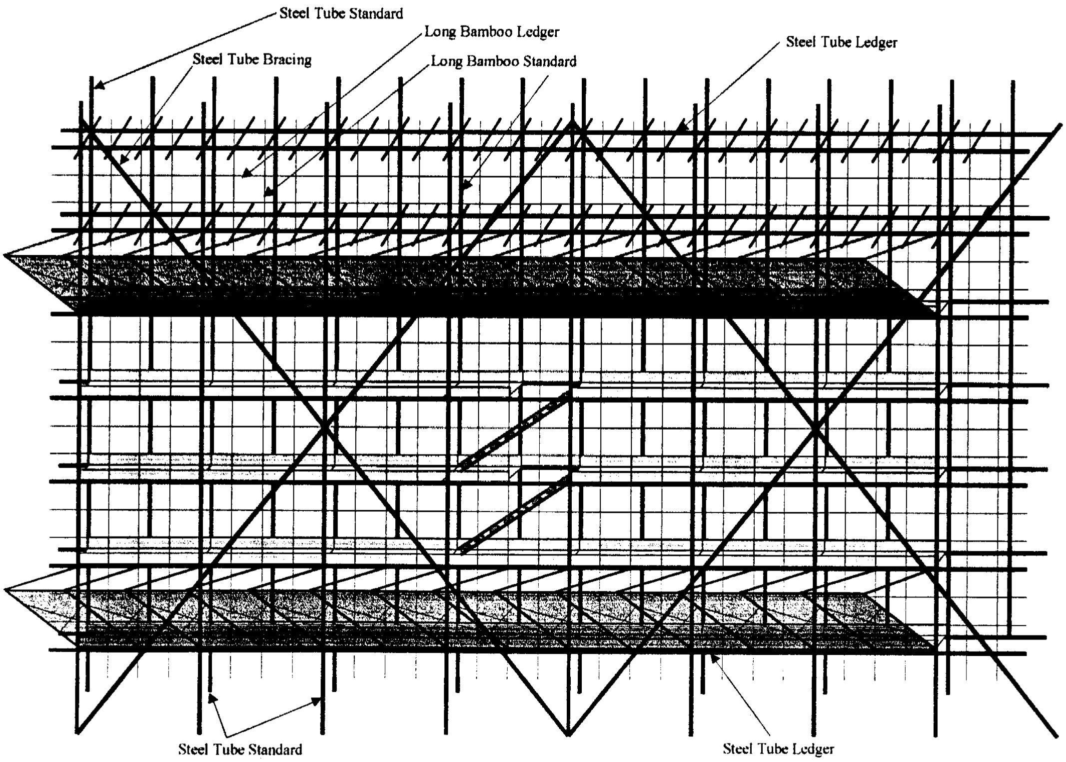

Figure 4.22 Typical diagram of a standard Metal-Bamboo Matrix System Scaffold (Source: Wui Loong, 2000)

The following table compares MBMSS with traditional steel scaffolding and traditional bamboo scaffolding.

	Traditional steel scaffolding	MBMSS	Traditional bamboo scaffolding
Catwalk	YES	YES	NO
Toeboard	YES	YES	NO
Stair access	YES	YES	NO
High reliability	YES	YES	NO
Flexibility	NO	YES	YES
Light weight	NO	YES	YES
High productivity	NO	YES	YES
Minimum of costs	NO	YES	YES

Table 4.2 Comparison of MBMSS with traditional steel scaffolding and traditional bamboo scaffolding (Source: Wui Loong, 2000)

4.4 Comparison of Traditional Construction Methods and Low Waste Technologies

A comparison between traditional construction and low waste technologies is given in Table 4.3.

Table 4.3 Comparison of Traditional Construction Methods and Low Waste Technologies

Process	**Traditional Methods**	**Low Waste Technologies**
Building Design	● Use of materials sizes does not correspond with the dimensions in the building ● Building components not standardized ● Down-stand beams and columns detrimental to large panel formwork system construction ● Specifications exceed the performance required Significant unnecessary mid-project variations	● With the standard modular approach, walls and slabs are standardized in both size an shape, being interchangeable between different building types ● Standardized building components ● Walls and flat slabs only, no down-stand beams and columns ● Modification of specifications to suit the contractor's available equipment and materials ● Less design variation

Formwork	• Conventional timber formwork • Double the cost of using steel panel in long run • Labour intensive for erecting and striking formwork • Longer construction duration • Plastering need for leveling concrete surface • Reused 8-15 times, several sets of timber forms needed for a high-rise block • Hand lift timber board from floor to floor • Considerable timber waste produced	• Large steel panel forms • High initial cost but balanced by the long terms savings in timber formwork • Less labour force required for erecting and striking formwork • High efficiency, twice faster than timber formwork system • Better quality concrete products, concrete surfaces suitable for applying tiles and paints directly • Reused over 100 times, one set of forms sufficient to complete a block and can be reused in another sites • Tower cranes needed for lifting formwork • Waste steel scrapped for recycling, less waste produced
Concrete Work	• In-situ placement • Time consuming • Higher labour cost • Poor quality, honeycombing often occurs • Plastering required before applying tiles and paints • More waste produced	• Precast concrete • Shorter 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
Masonry Work	• Brick walls or concrete block walls • Lower materials cost but higher labour cost • High skill levels • Thick layer of plaster needed • Time consuming • • More waste produced • • Walls with higher strength	• Internal drywall partitions • Higher materials cost but lower labour cost • Easy to install, low skill levels • Smooth surface and no plastering needed • 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 materials cost, easy to erect	• Steel hoarding • Expensive and demand higher labour force for

	● Less durable, about 2 years lifetime ● Low reusability, discarded after used once ● More timber waste produced	erection, but safe for passer-by ● More durable, about 4.5 years lifetime ● High reusability, waste steel scrapped for recycling ● 70% less waste
Scaffolding	● Conventional bamboo scaffold ● Lower initial cost ● High labour cost ● Less safe for workers ● More bamboo waste produced	● Gondola with Passenger Lift ● Higher initial cost, but balanced by saving in materials cost in the long run ● Less labour force required ● More safe for workers ● 80% less waste

4.4.3 Cost comparisons

The following are indicative cost comparisons between the items, taking 100% as the unit cost of the cheapest item in the comparison.

	Traditional Methods	**Vs**	**Low Waste Technologies**
(i)	Timber formwork 115% to 125%	Vs	Large panel steel formwork 100%
(ii)	Timber formwork 100%	Vs	Aluminum slab formwork 115% to 125%
(iii)	Timber formwork 100%	Vs	Semi precast slab 85% to 95%
(iv)	Insitu façade 115% to 125%	Vs	Precast façade 100%
(v)	Insitu staircase 110% to 120%	Vs	Precast concrete staircase 100%
(vi)	Traditional blockworks and plaster 100%	Vs	Drywall partition 170% to 190%
(vii)	Traditional plaster 100%	Vs	Spray plaster 110% to 120%
(viii)	Insitu cooking bench 110 to 120%	Vs	Precast cooking bench 100%

Table 4.4 Cost comparison of Traditional Methods and Low Waste Building Technologies

(Source: The Hong Kong Housing Authority)