Chapter 6

Construction Method Selection to Minimize Waste

This chapter investigates the possibilities to reduce the generation of waste by selecting construction methods.

According to a survey conducted by the Department of Civil and Structural Engineering of the Hong Kong Polytechnic University, in 2001, the last factor (among 6 factors) affecting the selection of construction methods was waste reduction. Waste minimization should be considered as an important issue when selecting construction methods. According to the same survey, timber formwork and wet trades (brick and block, tile and plastering) are identified as the major waste generation processes in the construction of buildings in Hong Kong.
The issue of waste minimization should be considered for waste arising from construction as well as demolition, thinking in advance of dismantling methods of buildings.

"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. Not surprisingly, recent research indicates that cost is the most important factor in selection of construction methods and technologies for building projects. The reduction of C&D waste is the least important factor according to 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."
(Source: Low Waste Building Technologies and Practices web site)

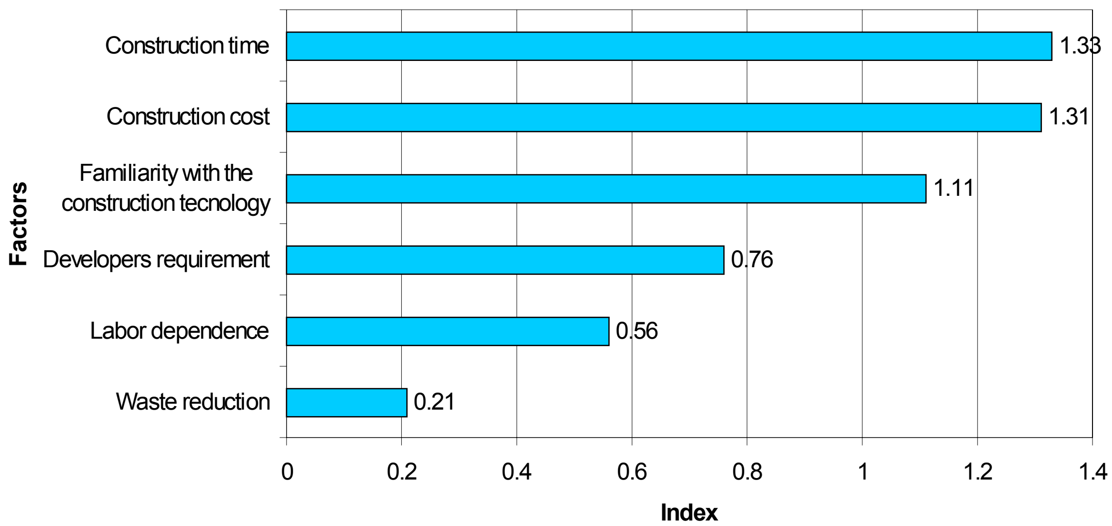

Figure 24: Factors that determined a construction method selection. (Source: Hong Kong Polytechnic University Survey)

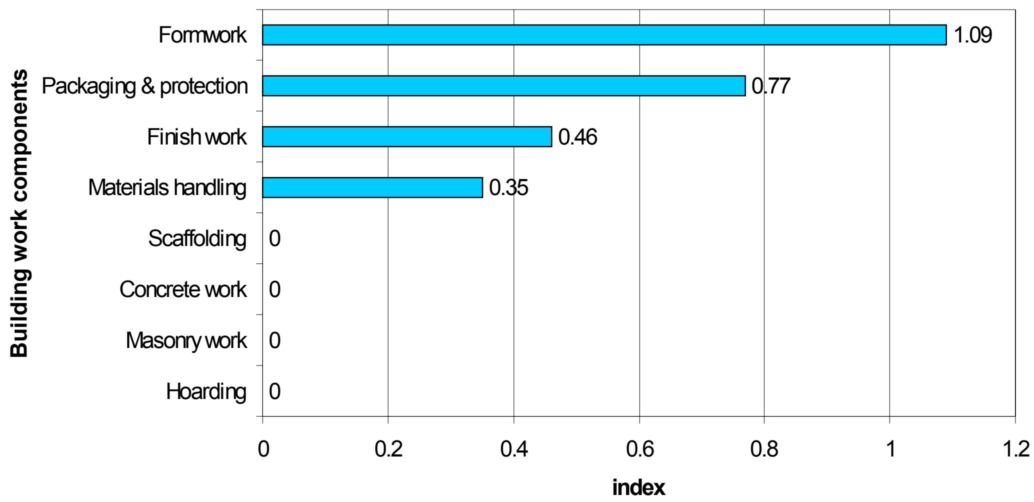

Figure 25: Building work components which are considered to be the most waste producing. (Source: Hong Kong Polytechnic University Survey)

6.1. On-site: hoarding, formworks and scaffolding

According to a survey conducted by the Department of Civil and Structural Engineering of the Hong Kong Polytechnic University, in 2001, "formwork" is the work component which is considered to be the most waste producing, followed by "packaging and protection", "finish work"…
Waste on site is also arising from wet trades which includes bricks and blocks, tiles, plastering…
For further information, please refer to the web site on "Low Waste Building Technologies" (http://www.cse.polyu.edu.hk/~cecspoon/lwbt).

Objectives

- **Minimize the generation of construction waste on site by selecting low waste construction methods.**

Waste Type

All types of waste arising from construction sites include:

- Timber boards from timber formworks.
- Steel bars from reinforcement bars.
- Bricks from brick and block works.
- Lightweight concrete from dry wall.
- Metals such as aluminum windows.
- In-situ concrete.
- Mixed cement.
- Plaster.

The main causes of waste generation on site are:

- Cutting.
- Abortive works.
- Material left over during processes.

Other causes related to material control such as improper storage and handling, over ordering…(Refer to chapter 5.1 "Material control").

Strategies

Formworks

· Avoid the use of timber formworks as it is not reusable (for many times) and generates waste on site.
· Allow the use of metal formworks such as steel or aluminum that is durable and can be reusable on site and on other sites for other projects, or scrapped for recycling.
· Consider early at the design stage the construction method such as for formworks, their size, handling; opportunities of reusing or recycling…this should be a determinant for the design.

Hoarding

· Allow the use of metal hoarding that can be reused or recycled afterwards.

Scaffolding

. Consider the use of metal scaffolding that can be easily reused or recycled.

Top and Middle: Metal fromwork.
Bottom: Metal scaffolding.

Benefits

Cost

· The initial cost is higher, but it is more durable and can be reused, also there is potential for recycling. It has to be considered as a long-term investment.

Environment

· It reduces waste disposed of at landfills.
· Therefore it extends the life span of landfills.
· Reduce pollution, energy used and noise from transportating disposal waste.

Others

. For metal formworks, the quality of concrete finishes is better compared with timber formworks.

Regulation

Practice Notes for Registered Contractors

· PNRC 25, Submission of Schedule of Building Materials and Products, December 1994.
· PNRC 21, Tropical Hardwood Timber, July 1992.
. PNAP 153, Tropical Hardwood Timber, July 1992.

References

Books

· **A Guide for Managing and Minimizing Building and Demolition Waste**, C.S. Poon, T.W. Yu, L.H. Ng, The Hong Kong Polytechnic University, May 2001.
· **Reduction of Construction Waste, Final Report**, C.M. Cheung, K.W. Wong, C.N. Fan, C.S. Poon, the Hong Kong Polytechnic University, March 1993.
· **Waste Minimization and Recycling in Construction, Design Manual**, P. Guthrie and S. Conventry, CIRIA Special Publication 134, London, 1999.
· **Waste Minimization in Construction, Site Guide**, CIRIA, Special Publication 133, London, 1997.
· **Waste Minimization in Construction, Training Pack,** CIRIA SP 148TP, London.
· **Waste Minimization and Recycling in Construction, a Review**, CIRIA Special Publication 122.
· **Waste Minimization and Recycling in Construction, Boardroom Handbook**, CIRIA Special Publication 135.
. **Waste Minimization and Recycling in Construction, Technical Review**, Stuart Coventry and Peter Guthrie, CIRIA PR 028.

Web sites

· Low Waste Building Technologies
http://www.cse.polyu.edu.hk/cecspoon/lwbt
· CIRIA, Construction Industry Research and Information Association
http://ciria.org.uk
· BRE, http://www.bre.co.uk

Other references

Inside

· Refer to chapter 5 “Material selection to minimize waste” and “Material control”.
. Refer to chapter 3.3 “Contractor’s attitude” and 3.4 “Designer’s attitude”.
. Refer to the “Low Waste Building Technologies” web site,
· Tung Chung Station Development Package One, Site 3.
· Tseung Kwan O Area 74 Phase 4.
· Tseung Kwan O Area 73A Phase 2.
· TKOTL 55 Area 72 Tseung Kwan O.
· Proposed Redevelopment Oxford House at Quarry Bay.
. Cheung Sha Wan West, Phase II.

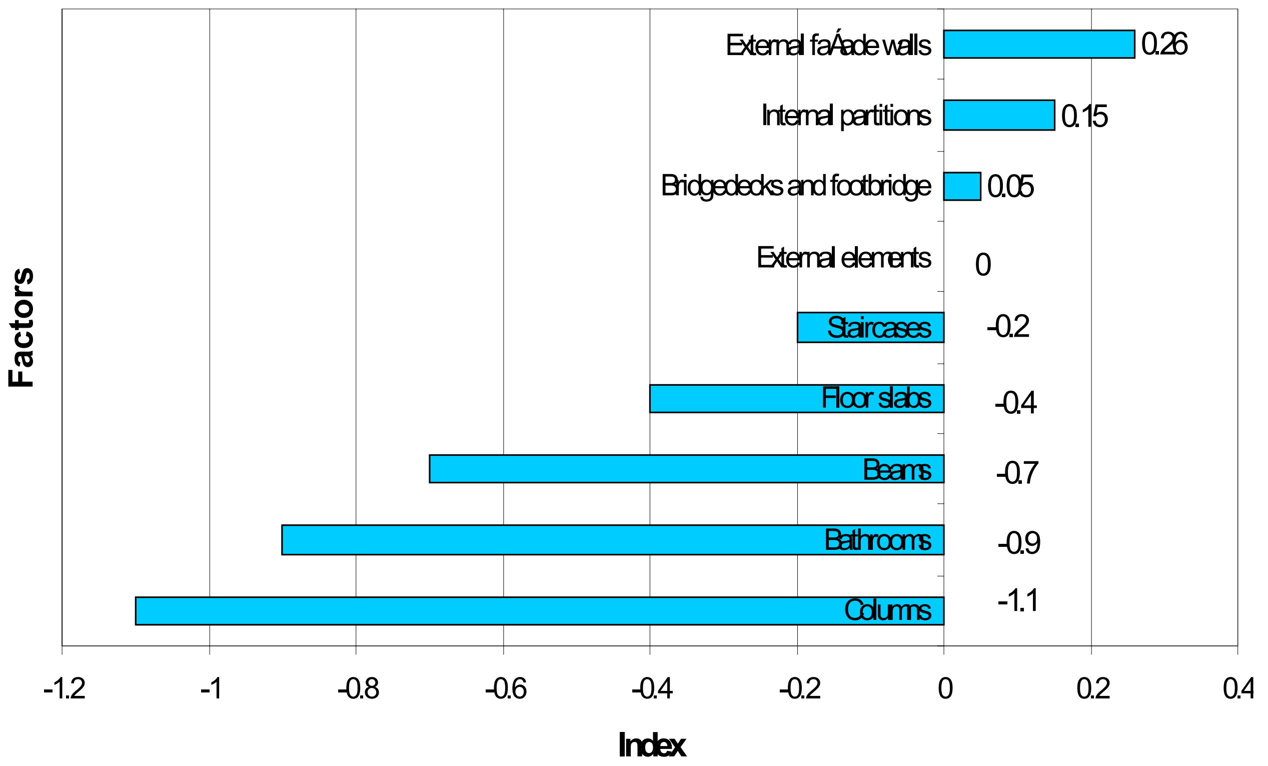

Figure 26: Frequency of use of the following precast elements in building construction in Hong Kong. (Source: Hong Kong Polytechnic University Survey, 2001)

Prefabricated facades

6.2. Off-site: precast and prefabrication

Moving the construction method on-site to off-site to a factory can reduce the generation of waste on site.

It requires experience, knowledge, early planning and early decisions in the design to allow sufficient time to set up the factory to start the production of prefabricated elements.
Prefabrication is highly applicable for high-rise building in Hong Kong in terms of financial benefits and improvement in construction.
According to a survey conducted by the Department of Civil and Structural Engineering of the Hong Kong Polytechnic University, in 2001, the most frequently used precast elements in building construction in Hong Kong projects are external facades, followed by internal partitions, bridgedecks and footbridges, external elements, staircases…

Objectives

- **Minimize the generation of construction waste on site by selecting off site construction methods.**

Waste Type

All types of waste arising from construction site include:

- Timber boards from timber formworks.
- Steel bars from reinforcement bars.
- Bricks from brick and block works.
- Lightweight concrete from dry wall.
- Metals such as aluminum windows.
- In-situ concrete.
- Mixed cement.
- Plaster.

The main causes of waste generation on site are:

- Cutting.
- Abortive works.
- Material left over during processes.

Other causes related to material control such as improper storage and handling, over ordering…(Refer to chapter 5.1 "Material control").

Strategies

- Consider early decisions in the design to allow sufficient time to set up the pre-fabrication yard moulds.
- Avoid last minute changes as it may generate a large quantity of waste as modules may already be built in the factory.
- Allow repetition in the design to facilitate construction and fabrication in the factory.
- Consider details such as assembly and disassembly to allow reuse or recycling. (See chapter 4.2. "Design for reuse and recycle").
- Consider dimensions of modules to allow transportation from the factory to the site.

Important:
The use of precast and prefabrication can reduce waste but must be carefully considered as it may be a problem to recycle such building components such as precast bathrooms.
In fact the notion of design for reuse and recycle should be considered.
For more detailed information refer to chapter 4.2 "Design for reuse and recycle".

Top: prefabricated facades, general view.
Bottom: left, prefabricated facades jointing detail and packaging, right, in situ joint wall.

Common types of prefabricated elements

(Source: Prefabrication Techniques for High-rise Residential Buildings, Chu R., Sparrow C.J., Environmentally Friendly Structures Seminar, May 2001, Hong Kong):

Facades:

There are various façade types in use around the world.

- **Beam type:** The beam type of a façade unit is suited to those areas of façade that require maximum opening width i.e. the width of the room is almost entirely glazed. The unit is cast-in to in-situ support structure on each side as the building is constructed and essentially acts in the same way structurally as if it were a conventional in-situ beam, supporting floor loads and possibly contributing to the lateral stiffness of the building. The in-situ shear walls or columns take loads from the beam to the foundations.

- **"Stitch-on" panel system:** The stitch-on panel system relies on in-situ construction to gain support. The system is a true panel and as such has vertical sections of precast concrete surrounding windows within the panel. Generally the panels present a consistent façade finish with vertical precast to in-situ concrete joints. Horizontal precast to precast joints are overlapped and grouted at the rear, with the whole façade face sealed. The panels distribute floor loading through the top section of the panel, which acts like a beam, and then in shear action to the vertical in-situ support elements each side. This type of panel has been used extensively by the Hong Kong Housing Authority.

- **"Clip-on" panel system:** The clip-on panel system is so called as it is attached to the building after the structure is built. Usually the panels are supported individually from small corbels or steel brackets at the bottom of the panel and restrained against lateral movement with steel brackets at the top. This system is more widely used overseas and incorporates a "drained joint" whereby no external seals need be used. As the panel is post-fixed the structure must be self-supporting, with the panel only having to support itself. The system must by necessity incorporate an edge beam. The panel is independent from the structure and as such it allows more useable floor area with the same overall Gross Floor Area.

- **Load-bearing panel system:** This system is not used widely in Hong Kong presently. It lends itself to low-rise buildings, possibly up to 20-storeys in height. A central core or separate system of shear walls usually affords the building wind resistance, and the load-bearing precast panels take vertical load only. The necessary transfer of load between panels is taken by grouted bearing joints and grouted location dowels and,

- **Lost from panel system:** This system allows a precast finish to the outside of an external shear wall. The panel can be thinner than the panel types above, replacing the external shutter of the wall. The panel is tied to the internal shutter prior to pouring concrete.

Care should be exercised when utilizing a mixture of the various types of panel above as the joint system so formed may be difficult to be waterproof.

Floors

The most common types of precast floor system used in Hong Kong are partial precast slabs. These slabs are generally 50mm to 75mm thick. They are lifted in place and supported off the floor below. They come with the bottom reinforcement cast-in the panel, so that top reinforcement only is required to be fixed. In-situ concrete is poured on top and when cured the two act compositely to form the slab. The stiffness of the partial slab can be increased through the use of cast-in lattice girders, which increase the effective depth of the unit prior to concreting and may result in less propping.

Stairs

Precast stairs are used extensively in Hong Kong. A variety of details have been developed depending on the layout. These incorporate either in-situ, totally precast or partial precast composite landing slabs. Support corbels are used at precast to precast connections and in these locations headroom may become critical.

Benefits

Cost

- Increase cost effectiveness (for high-rise buildings).

Environment

- Reduce the amount of waste produced on site (remoce packaging) and therefore the waste disposed at landfills.
- Reduce transportation of disposal waste (less pollution, energy used and noise).
- Minimize impact of construction works on the surrounding environs.

Others

- Construction practice: increase speed, quality, on site safety.
- Construction management improved through quality control, planning complexities and speed restraints.

Regulation

Practice Notes for Registered Contractors

- PNRC 25, Submission of Schedule of Building Materials and Products, December 1994.

British Standards

- BS 6073, 1981, Specification for Precast Concrete Masonry Units.

References

Books

- Prefabricated Modules in Construction, A Study of Current Practice in the UK, R. Neale, A. Price and W. Sher, The Chartered Institute of Building, 1993.

Journals

- Innovative Plug-in Connections – The Key Technology for Prefabricated Housing, Prochiner F., Walczyk R., Hartmann D., Detail Magazine 4, 2001.
- Diversity with Systems – Glass-Fibre-Reinforced Concrete Facades, Reichel A., Detail Magazine 4, 2001.

Other references

Inside

- Refer to chapter 4.3.2 “Modular design”.

List of examples

- COSI, Center of Science & Industry, Columbus, Ohio, USA, Arata Isozaki & Associates.

"The eastern façade of the building, which faces the city center, includes part of the restored old high school, and on the western side the external wall is formed by a shell with an elliptical plan and a clothoid-curve section. This 300m long western wall is made up of 177 pieces of 20m-high precast concrete sections of six different types, connected with stainless-steel jointing rods. To improve the precision of the finishing, the detailing took into account local construction methods, prefabricated materials were used as much as possible, and the construction system was simplified". (Source: The Japan Architect Yearbook 2000).

Refer to the "Low Waste Building Technologies" web site, for detailed information:
http://www.cse.polyu.edu.hk/cecspoon/lwbt

In Hong Kong:

- Cheung Sha Wan West, Phase II.
- Residential Development, "Les Saisons", at Aldrich Bay Reclamation.
- Sau Mau Ping Estate Redevelopment Phase 5.
- Shek Yam Estate Phase 3.
- Tseung Kwan O Area 73A Phase 2.
- Tseung Kwan O Area 74 Phase 4.

In Overseas:

- Gifu Kitagata Apartment Building Sejima Wing, Kitagata, Motosu-gun, Gifu Prefecture, Japan.
- Gifu Kitagata Apartment Building Takahashi Wing, Kitagata, Motosu-gun, Gifu Prefecture, Japan.
- Wozoco's Apartment.
- Nemausus Experimental Scheme, Nîmes, France.
- Rokoo Housing Phase I-III.

(Left) Prefabricated toilet, (Right) Prefabricated staircases.

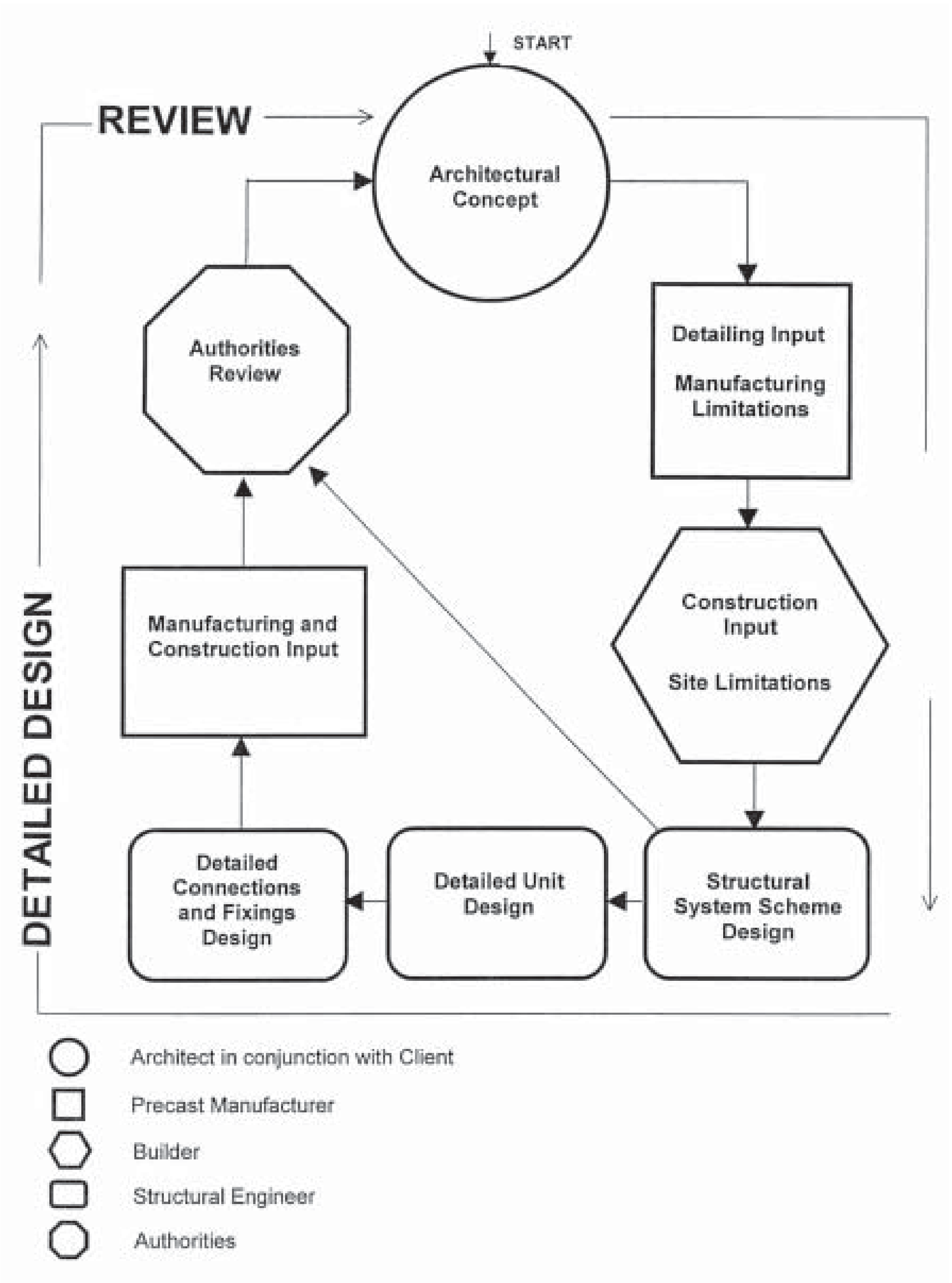

Figure 27: Design Model for Precast Concrete (Source: R. Chu, C.J. Sparrow, Prefabrication techniques for high-rise residential buildings).

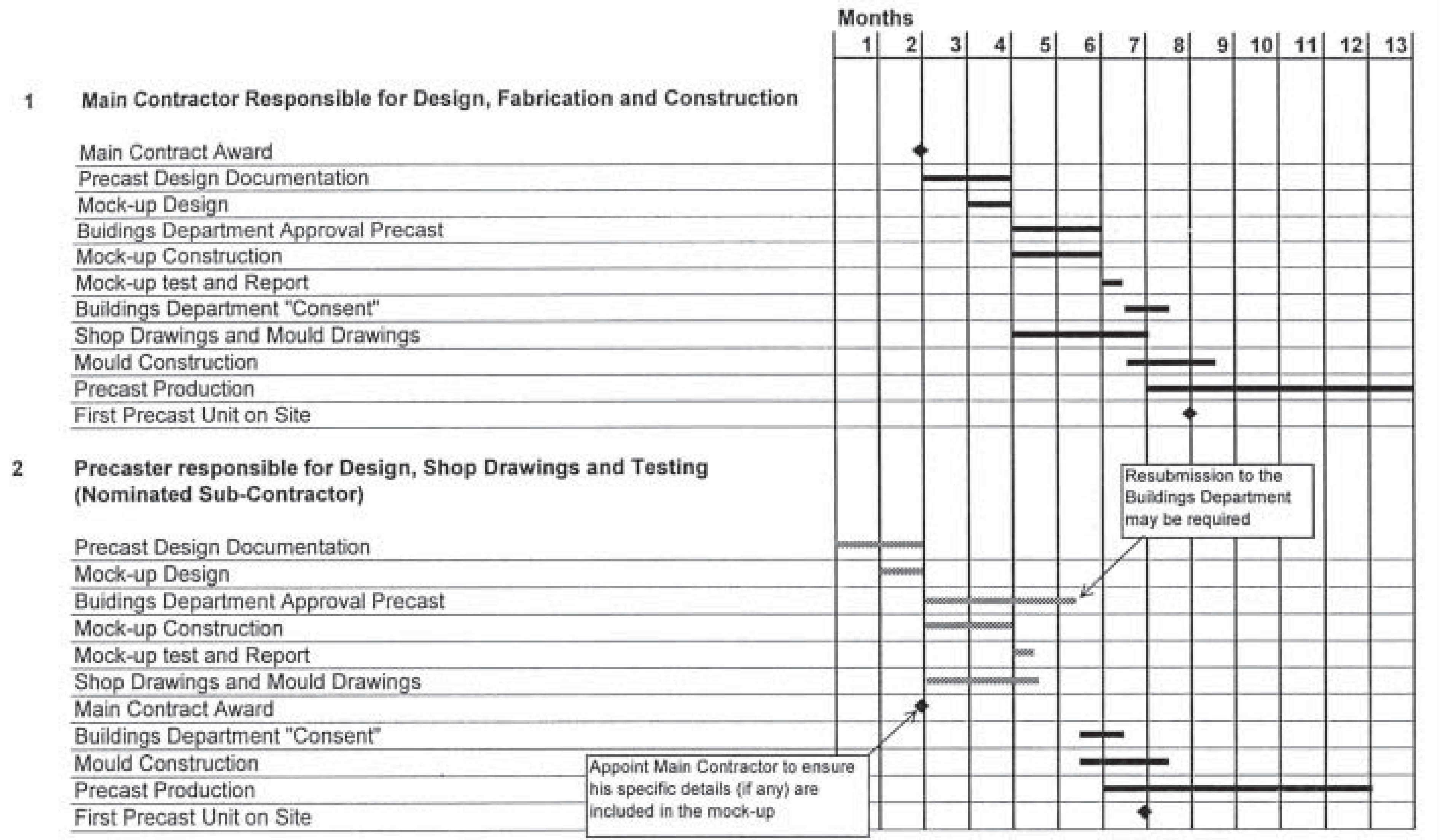

Figure 28: Precast Facade Design and Production Programmes (Source: R. Chu, C.J. Sparrow, Prefabrication techniques for high-rise residential buildings).

Types of Façade	Pros	Cons
Beam Type Facade	• Maximizes window area, as no vertical precast panel elements are required. Often complies best with architectural intent of residential buildings. • Relatively light and compact, therefore easier to transport and cheaper. • Requires no "special" Building Department Approval as it replaces insitu construction entirely	• Results in variable height between floors. Therefore there may be a higher risk of leakage at the window connections. • Windows will abut both precast and insitu concrete resulting in a higher risk of leakage. • Relies on beam reinforcement tying in with insitu concrete, which can lead to congestion and erection delays. • Units required as construction proceeds, which may lead to delays in the whole project if the precast concrete production is delayed. • Hard to match finishes at insitu connection if beam is pre-finished prior to erection.
Stitch-on Panel System	• More easily weatherproofed than Beam option as windows are contained entirely within precast. • Consistent façade finish and appearance can be achieved.	• Some impact on architecture may be experienced due to requirement for vertical elements of precast around window openings. • Requires support/shear walls at each end, which may result in loss of flexibility. • Units required as construction proceeds, which may lead to delays in the whole project if the precast concrete production is delayed. • Weatherproofing relies on good compaction of insitu concrete at precast interface. • Face sealing from gondolas or scaffolding required.
Clip-on Panel System	• Consistent façade finish and appearance can be achieved. • No external sealant required. Drained joint possible. • GFA/useable floor area benefits may be achieved. • Allows more time for precast manufacture as construction may proceed independently. • Quick to install with adequate tolerances. • More easily weatherproofed than Beam option as windows are contained entirely within precast.	• Some impact on architecture may be experienced due to requirement for vertical elements of precast around window openings. • Insitu beam required in rooms at the head. • Top restraint will require fireproofing. • Not widely used in Hong Kong. • Access required to the rear of the panel to ensure rear seal is correctly carried out during construction. • Ability of the drained joint to perform under test wind pressures may be hard to achieved depending on configuration. • Fire stop and sound seal required.
Load-bearing Panel System	• More easily weatherproofed than Beam option as windows are contained entirely within precast. • Consistent façade finish and appearance can be achieved. • Dispenses with insitu load-bearing walls.	• Height of building limited to about 20 storeys if "normal" thickness panels used. • Some impact on architecture may be experienced due to requirement for vertical elements of precast around window openings. • Units required as construction proceeds, which may lead to delays in the whole project if the precast concrete production is delayed. • Face sealing from gondolas or scaffolding required.
Lost Form Panel System	• Does not require scaffolding to fix finishes. • Is not GFA accountable. • Allows compatibility of finish with other types of precast.	• Requires grout sealing. Loss of grout can cause staining and/or poor compaction of concrete. • Increases load to the foundations. • May require tie holes through precast depending on the construction method.

Table 6: Advantages and disadvantages of precast facade systems (Source: R. Chu, C.J. Sparrow, Prefabrication techniques for high-rise residential buildings).

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<table>
<tr><th colspan="2">FAÇADE TYPE</th></tr>
<tr><th>PRECAST</th><th>INSITU</th></tr>
<tr><td>Costs for precast from the Precaster usually include the following:
• Fully finished precast (This could be "architectural" precast or pre-tiled),
• Stainless steel fixings (Grade 304),
• Sealant, back-up rods and baffles,
• Manufacture of moulds,
• Installation of window frames,
• Design and shop drawings,
• Manufacture, storage in their yard, and delivery,
• Installation.

The following should be added into the cost of the precast obtained from the Precaster where appropriate:
• Fire spray of brackets where required,
• Fire stopping between floors,
• Supply of window frames,
• Supply and installation of glass, and
• Interior finishing (Note some precast panels are formed on the inside face and require no subsequent plastering).

The use of precast will also yield the following savings, which should be evaluated:
• Value of extra sellable space due to "clip-on" and lost formwork systems being exempt from GFA calculations,
• Reduced project finance cost due to reduced construction period,
• Greater speed to market allowing apartments to be sold earlier,
• Reduced number of formwork carpenters and steel fixers on site,
• Reduce waste to be disposed of,
• Reduced general site overhead,
• Elimination of scaffolding,
• Elimination of formwork, and
• Elimination of falsework.</td><td>Insitu façade costs should include the following:
• Supply of concrete,
• Site delivery of concrete to workface,
• Placing of concrete,
• Supply and placing of reinforcement including ties,
• Cut and bend reinforcement,
• Welding and spacers,
• Purchase of formwork,
• Erection and preparation of formwork,
• Vibration of concrete,
• Supply of cast-in items for fixing of window frame,
• Supply and fix window frames,
• Supply and fix glass,
• Supply and fix of external finish i.e. tiling,
• Repairs to insitu concrete,
• Purchase of falsework,
• Erection of falsework,
• Removal of formwork,
• Removal of falsework,
• Erection of scaffolding,
• Removal of scaffolding,
• Sealant and back-up rods, and
• Interior finishing.</td></tr>
</table>

Table 7 – Cost Items for Precast and Insitu Concrete Facades (Source: R. Chu, C. J. Sparrow, Prefabrication techniques for high-rise residential buildings).

Case Study 21

Integer Pavilion, Admiralty, Hong Kong

Title:	Integer pavilion, Hong Kong.
Location:	Tamar Basin, Admiralty, Hong Kong.
Architects:	Integer (UK), Leigh & Orange Ltd.
Structural engineer:	WSP Hong Kong Ltd.
E&M engineer:	WSP Hong Kong Ltd.
Main Contractor:	Gammon Construction Ltd.
Quantity surveyor:	Franklin + Andrews.
Year:	2001
Contract Sum:	HK$ 40,000,000.
Contract Period:	9 months.
Site Area:	4770 m2.
Gross Floor Area:	1938 m2

Project description/Scope of works:
3 storeys high building using concrete modules and structural steel frame, laid with precast slab panels, enclosed by glass wall and metal roof cladding, filled with furniture and building services.
The Pavilion is a demonstration project for intelligent and green construction, which includes exhibition areas as well as demonstration flats. The main idea of the project regarding the waste issue is to reduce the generation of construction waste as well as demolition waste.

Construction waste is minimized by the use of:

- Prefabrication of elements and assembly on site (e.g. structural steel elements, concrete panels...)
- Prefabrication of concrete modules, including the fitting out and finishes, assembly on site.
- Structural steel, which can be easily assembled without the generation of waste from cutting on-site.
- Permanent formworks for the foundations.

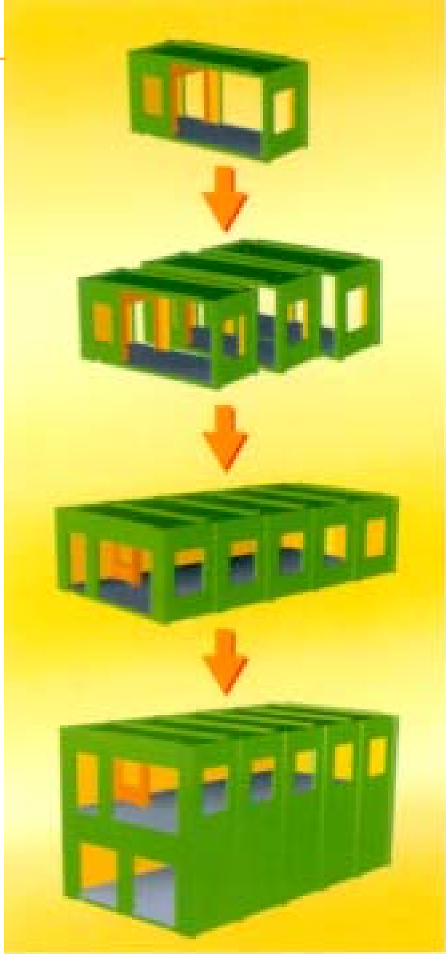
Demolition waste is minimize by the use of:

- Disassembly concept, to reuse the pavilion at another place.
- Steel structure, which can be easily dismantle for reuse and recycle.
- Sustainable materials, which can be recycled.

The pavilion includes:

- Foyer.
- Conference room.
- Exhibition area.
- Gallery.
- Lift lobby.
- 2 finished demonstration flats.
- Sky garden

For further information, visit the pavilion and see the web site: www.integer.com.hk



Extract from Integer web site: www.integer.com.hk
"A range of intelligent technology features has been used throughout the Integer Pavilion in Hong Kong. The aim is to create a realistic and flexible network of intelligent technologies, which could be integrated into new residential developments today, to improve building and energy efficiency."
Construction stage
"Lengthy, large scale and noisy construction sites are a feature of everyday life in Hong Kong. Reducing time on site, the industrial waste generated and noise levels are leading factors in minimizing the impact of construction sites o the environment and on the residents of Hong Kong.
Gammon Construction has developed a method of construction, showcased at the pavilion, that is based on prefabricating large modular elements of a high-rise building off site in factory controlled conditions. Delivered to site substantially equipped with fixtures and fitting, these modules can be rapidly assembled, connected and finished to form the completed building. Shifting the focus of activity from site to factory is this fashion achieves considerable benefits, including:

- *Faster construction that is less disruptive to the surrounding community.*
- *Better homes, both in terms of quality and finish and noise insulation.*
- *Less waste.*
- *Less noise.*
- *Fewer accidents on site.*
- *More energy efficient.*
- *Lower cost.*
- *Greater scope for recycling.*

Extract from the article "Moving construction offsite – modular construction" Peter Moore.
Gammon Construction has been carrying out research for new products and methodologies including modular construction.
In 1998, Gammon Construction propotyped a bathroom module for a Housing Authority project and in conjunction with Ove Arup undertook a study to convert an entire standard Hong Kong residential tower into a modular design.
For the Integer pavilion, Gammon are producing 20 modules which are grouped into five module series, providing at ground floor level a meeting room and toilet facilities, while at first floor level two residential units of 700 sq. feet each will be erected above the lower modules.
Modules specifications:

- *Size – 8.5L x 2.5W x 2.75H (internal).*
- *Weight – 25t max.*
- *36 modules per floor.*
- *15 module types.*
- *Grade 40 concrete.*
- *Floor & Façade 125 mm.*
- *Roof & Walls 75 mm.*

Left page: (top) General view of the pavilion under construction. (Middle) Prefabricated modules. (Bottom) Detail facade.

Right page: (top) Module assembly 3D image, source the Integer brochure. (Middle) left, inside module, joint detail, right, jointing system of modules, external view. (Bottom) left, facade system, right, metal scaffolding and foundations.