Chapter **4.3**

Minimizing Waste from construction in the Design

4.3.1. Dimensional coordination and standardization
4.3.2. Modular design
4.3.3. Minimizing temporary works
4.3.4. Avoid late design modifications
4.3.5. Detailing design

This chapter investigates the possibilities to reduce waste arising from construction, by design measures and concepts such as dimensional coordination and standardization, modular architecture, minimizing temporary works, avoiding design modifications and detailing design.
The idea is to take more consideration in the design to reduce the generation of waste. It is better to consider waste minimization measures before the waste is generated, and it is less expensive.
Waste arising from construction is also related to material selection as well as construction method selection, which are described in chapters 5 and 6.

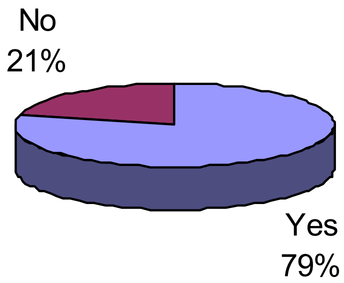


Figure 13: Consideration at the design stage of design dimensions to match with the materials size standards to avoid cutting. (Source: Hong Kong Polytechnic Survey, 2001)

Dimension/Space	**Range of space**	**Multiples of size**
Zones for columns and load bearing walls	100 to 600 mm	3 M or 1 M
Centres of columns and walls zones	From 900 mm	3 M or 1 M
Spaces between columns and walls zones	From 600 mm	3 M or 1 M
Openings in walls (e.g. for windows and door sets)	From 600 mm	3 M or 1 M

Table 4: Modular sizes for horizontal coordinating dimensions of space (Source: BS 6750: 1986 table 2)

Dimension/Space	**Range of space**	**Multiples of size**
Floor to ceiling and floor to floor (and roof)	Up to 3600 mm	1 M
	From 3600 to 4800 mm	3 M
	Above 4800 mm	6 M
Zones for floor and roof levels	100 to 600 mm	1 M
	Above 600 mm	3 M
Changes of floor and roof levels	300 to 2400 mm	3 M
	Above 2400 mm	6 M
Openings in walls (e.g. for windows, including sills and/or sub-sills, and for door sets)	300 to 3000 mm	3 M or 1 M

Table 5: Modular sizes for vertical coordinating dimensions of spaces (Source: BS 6750: 1986 table 3)

4.3.1. Dimensional coordination and standardization

Dimensional coordination can reduce the generation of construction waste. According to a survey conducted by the Department of Civil and Structural Engineering of the Hong Kong Polytechnic University, 79% of the respondents (mainly architects and structural engineers) consider at the design stage, design dimensions to match the materials size standards to avoid cutting. Still cutting on site generates a large quantity of waste.

Objectives

- **Avoid dimensional disco-ordination generating excessive cutting to reduce the generation of waste.**
- **And avoid visual discomfort created by dimensional disco-ordination.**

Waste Type

Cutting waste generated at the construction stage and in internal and external renovations (finishes) such as:

- Timber board from timber formworks.
- Steel bars from reinforcement bars.
- Bricks from brick and block works.
- Lightweight concrete from dry walls.
- Tiles from floor, ceiling and wall tiling.

Strategies

Dimensional coordination should be carried out at an early stage when designing the building to match material size and design dimensions. It can also be done when designing interior finishes for refurbishment (e.g. tiling). "It is a system of arranging the dimensional framework of a building so that components can be used within a framework in an inter-related pattern of sizes" (D. Osbourn).

Design

- Consider at an early stage of the design, material coordination to avoid cutting.
- Check with the contractor the sizes of materials available.
- Forward and backward process of checking material sizes and design dimensions.
- Prepare specifications and detailed drawings showing material fitting, in advance.
- Look for alternatives for material and construction methods such as prefabricated tiling to avoid extra cutting.
- Avoid wastage through incorrect and over specification of materials (a good knowledge or information on material size and availability is important).
- When designing dimensional coordination think of buildability (e.g. do not forget the joining space).

Construction

- Avoid the use of timber formworks, which creates waste from cutting; prefer the use of system formworks (metal or aluminum), which can be reused.
- Use prefabrication such as facades, staircases… and tiling if possible.

Left, Timber cutting formwork. Right, Tling waste from cutting.

"Do building systems play a role in your current projects?"
"The answer here is a clear "yes". In the first instance, a building system is not a material entity; it is a mental approach to construction. System thinking means looking at complex things in such a way that one can comprehend the various parts that go to make them up – and the relationship between the parts – in terms of the task they have to perform. In that sense, every building we design is a building system for me. But to take advantage of a systems approach, one has to develop the parts and the sets of relationships between them in such a way that friction, redundancy and inefficiency are avoided in all phases of the construction; in other words, in the manufacturing and assembly processes, and in use."
"What requirements do you make of modern building system?"
"A system should acquire an efficient functional form through the definition of the parts and their relationships to each other. This form should be appropriate to the processes of manufacture and assembly and should facilitate the construction of a satisfying, expressive building with a minimum use of materials and energy."
"What developments do you foresee in the future?"
"…Nevertheless, industrialization is steadily advancing in the building sector – without architects heeding it very much. The systems concept is asserting itself at least at the level of subsystems. The co-ordination of the parts in a curtain wall façade system is an example of this. What is still lacking is systems thinking on a comprehensive scale for buildings as a whole. That explains why, in the manufacture of technical systems, "traditional" construction, as it is known often more efficient than closed building systems, regardless whether they have been developed by architects or building firms."
(Source: Open and Closed Systems – an Interview with Helmut Schulitz, Interviewed by Christian Schittich, Detail 4, 2001).

Be careful:
Dimensional coordination can be difficult if materials are reused. They may not be standard materials with standard sizes such as old bricks or stones. It takes more time to arrange positioning but the result will be better (improved attractiveness).

Building system definition:
This includes design rules and a product system whose parts have compatible interfaces thus permitting the use of several alternative components and assemblies. The compatibility of the components and assemblies is assured by means of dimensional and tolerance system as of connections and joints.

Benefits

Cost

- Savings on material usage (less cutting).
- The generation of waste on site is reduced, and hence creates less sorting on site, and less transportation of waste to landfills.

Environment

- Reduces waste disposed to landfills.
- Less pollution created by transportation of waste to landfill, and less energy used and less noise.

Others

- It avoids visual discomfort created by dimensional disco-ordination.
- The use of good standard materials can allow reuse.

Regulation & Standards

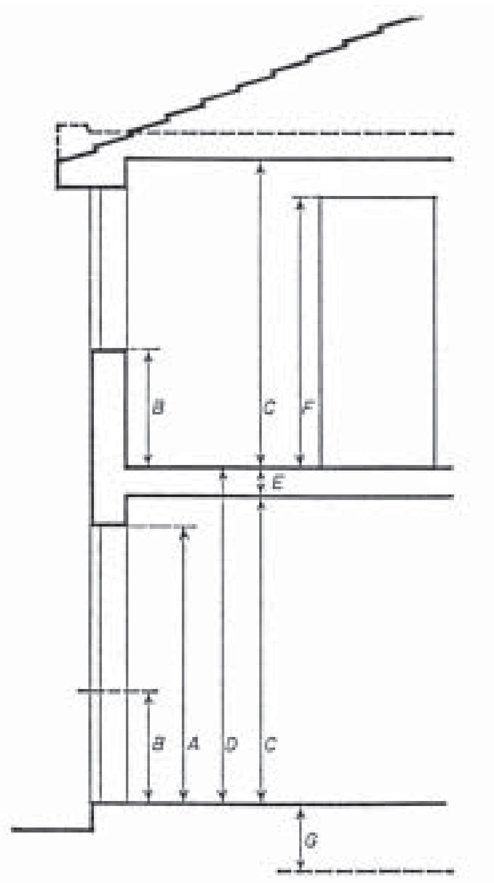
The British Standards give detailed information on dimensional co-ordination and modular co-ordination:

- **British Standards BS 4606**, 1970, Recommendations for the Coordination of Dimensions in Building.
- **British Standards BS 4643,** 1970, Glossary of Terms Relating to Joints and Jointing in Building.
- **British Standards BS 5568,** Building Construction – Part 2, 1978, Modular Co-ordination. (Specification for co-coordinating dimensions for stairs and stair openings).
- **British Standards BS 5606,** 1987, Accuracy in Building.
- **British Standards BS 6750,** 1986, Specification for Modular Co-ordination in Building.
- **British Standards PD 6446,** 1970, Recommendations for the Co-ordination of Dimensions in Building. Combination of Sizes.
- **British Standards DD 51**, Guidance on Dimensional Coordination in Building.
- **British Standards DD22,** Tolerances and Fits for Building; the Calculation of Work Sizes and Joint Clearances for Building Components.

References

Books

- Brookes A. J., *A Students' Guide to Dimensional Co-ordination, National Building Agency* (London, 1978).
- P. Goodacre, *Cost Factors of Dimensional Co-ordination, Report of Science Research Council Project 1976-1980*.
- Guide E577-85, *Standard Guide for Dimensional Coordination of Rectilinear Building, Parts and Systems*, ASTM 1999 (American Society for Testing and Materials) (available on http://www.astm.org).
- H. King and D. Osbourn*, Components*, Mitchell's Building, 1979 and 1989. London.
- Sarja A., *Open and Industrialised Building*, E & FN Spon, London, 1998.



A -Window head height
2300 I
2100 II

B-Window sill height

0	1000
200	1100
600	1200
700	1400
800	1800
900	2100

C-Floor to ceiling height
2500
2400
2350
2300
2100 (garages only)

D-Floor to floor height
2600-mandatory height
for public sector housing 2700

E-Floor thickness
200
250
300

F-Door set height
2100

G-Change of level

300	1700
600	1800
900	2000
1200	2100
1300	2300
1400	2400
1500	

Figure 14: Vertical controling dimensions for housing (Source: Components, Osbourn).

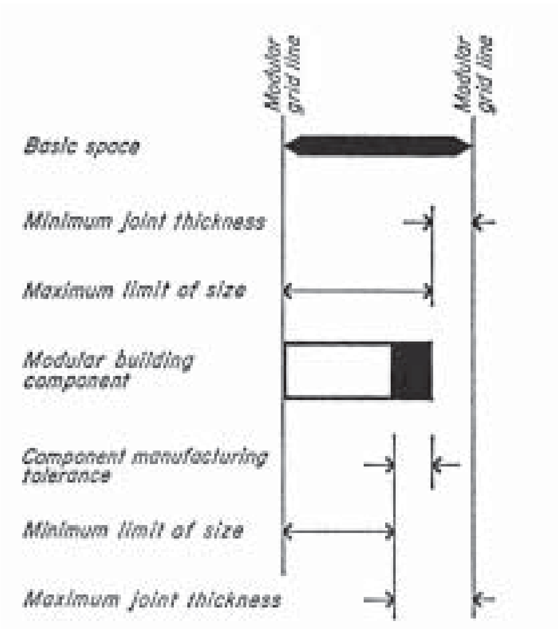


Figure 15: Relationship of modular building component to a planning grid, (Source: Components, Osbourn).

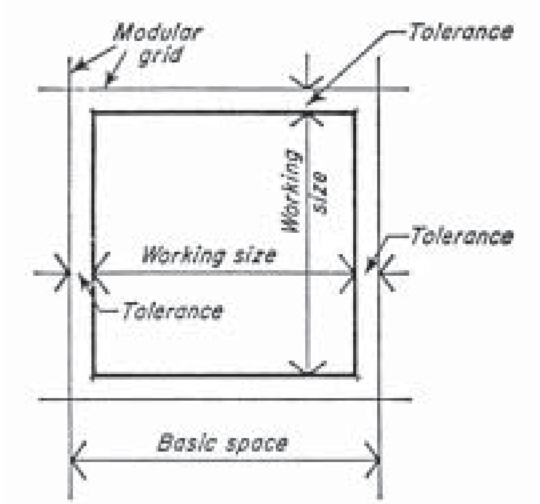


Figure 16: Space relationship component to grid. (Source: Components, Osbourn).

Journals

- Open and Closed Systems – an Interview with Helmut Schulitz, Interviewed by Christian Schittich, Detail 4, 2001.

Web site

- CIRIA, http://www.ciria.org.uk
- BRE, http://www.bre.co.uk

Other references

Inside

- Refer to chapter 6.2 on "Off site: Precast and Prefabrication".
- Refer to chapter 4.3.2 on " Modular Design and Modular Architecture".
- Refer to chapter 4.2.2 on "Design flexibility".

Outside

- Refer to architecture using building system.
- TEN media, Standardization and Modularization (part 1& 2), Video, 1996, (available on BRE web site).
- BRE, The Use of Modular Building Techniques for Social Housing in the UK a Market Research Report, Alan Gilham, 2000.
- Mc Graw-Hill Publishing, Builder's Guide to Modular Construction, Hutchings, 1996, (available on BRE web site).
- CIRIA, Standardization and Pre-assembly: Client's Guide and Toolkit, C544, 2000.
- CIRIA, Standardization and Pre-assembly: Adding Value to Construction Projects, R176, 1999.

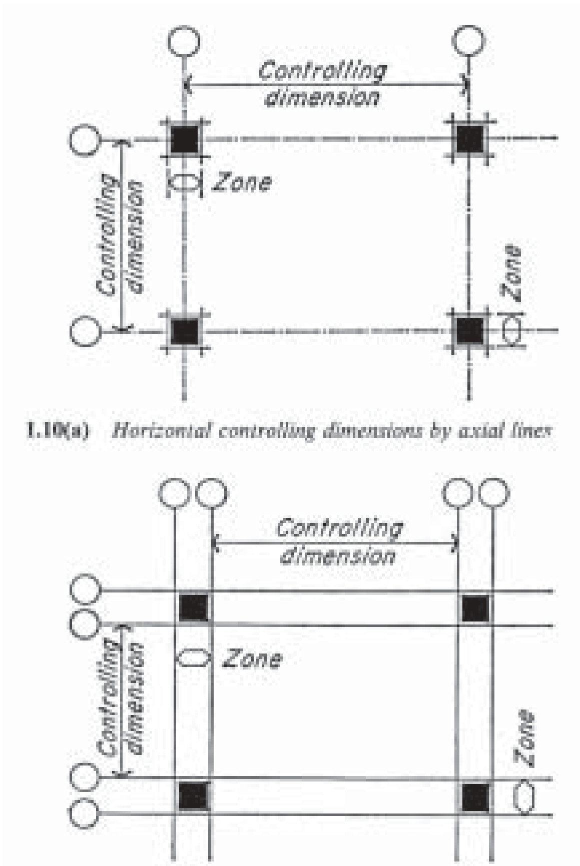


Figure 17: Horizontal controlling dimensions by axial lines, and horizontal controlling dimensions by zoned boundaries (Source: Components, Osbourn).

- *Habitat expo 67, Moshe Safdie, Montreal, Canada.*

"Habitat is a major domestic development in Montreal, Canada, built in conjunction with Expo 67. The design resembles a randomly placed pile of 354 boxes, incorporating 158 dwellings of various sizes and types. The boxes are all of the same basic dimensions (38' 6"x17'6"x10'0") and were made of reinforced concrete. The flour walls and floor were poured in one mould, and the roof added with another. The interiors were prefabricated and to the maximum possible degree. Bathrooms and cloakrooms were factory-made glass fibre boxes. The interiors were designed to be fitted out at ground level, so that the completed box could then be placed in position. The contractors tried placing the box before fitting it out, but eventually came to the conclusion that it was easier to do more work on the ground, before positioning the box in the building.

Problems were experienced when trying to integrate the services within such a structure. The architect (Moshe Safdie) pointed out that the system needed much more prefabrication and pre-assembly in electric and mechanical services. There were also problems with the structure. In the original design, for a much larger development of 1000 dwellings, the boxes were to be placed in A-frames with independent structures carrying all the structural loads. In the smaller scheme, the number of variations in the design of the boxes, were caused by the varying loads due to height and the randomness of the arrangement of the boxes".

(Source: Prefabricated modules in construction)

4.3.2. Modular design

The use of modular construction and modular design can reduce the generation of waste arising on construction sites as fabrication is carried out at factories. There are some important issues to consider such as the transportation of modules in dense urban areas (dimension of modules), the jointing system between modules and the opportunities of reusing and recycling modules.

Objectives

- **Reduce construction on site, and move construction off-site.**
- **Minimize the amount of waste generated at the construction stage.**
- **Integrate modular construction in the design.**

Waste Type

Type of waste generated on site at the construction stage by non-modular design.
(Modular design allow the use of prefabrication techniques and modular construction)

- Timber from timber formworks.
- Steel from reinforcement bars.
- In-situ concrete.
- Bricks.
- Mixed cement.
- Plaster.
- Tiles.

Strategies

Design

- Consider the use of repetitive design or modules to facilitate construction.
- It is highly applicable for high-rise buildings in Hong Kong.
- Consider the form and dimensions appropriate to the processes of manufacture and assembly (transportation from the factory to the site).
- Allow diversity in balcony design for example to avoid monotony.

Material selection

- Consider the unity of the construction: the use of a single building material for everything (e.g. steel frame can be built with the same tolerances as the façade, so it can fit together).

Benefits

Cost

- Increase cost effectiveness.

Environment

- Less waste produced on site (and less packaging), less waste disposed of at landfills.
- Extends the life span of landfills.
- Less transportation of disposal waste (less pollution, noise and energy used).
- Minimize impact of construction work on the surrounding environs.

Others

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

- *Innovative Plug-in Connections – The Key Technology for Prefabricated Housing, Prochiner F., Walczyk R., Hartmann D., Detail Magazine 4, 2001, p. 701-707.*

"As part of a project being conducted at the University of Technology in Munich and supported by the Federal German Ministry for Education and Research, a quick, plug-in connection unit is being developed that will facilitate the erection of housing in record time. It should be possible in the future to take a building into occupation after only 24 working hours; in other words, three days after the commencement of construction. The first day would be taken up by the actual assembly work, the second day by the fitting out and finishing, and the third day by the occupants moving in. The new quick-connection unit, for which a patent has been applied, will allow a simultaneous coupling not only of the building elements, but of all the systems integrated within them, such as heating and electrical installations and control networks."

"This system reveals a number of advantages over traditional forms of construction and assembly:

- *It is faster: the construction period is reduced to three days; service installations are prefabricated and incorporated more swiftly; and building firms are less dependent on the weather and time of year.*
- *It is more economical: the shorter assembly period represents a big potential costs saving; and life-cycle costs are reduced as a result of the simple method of removal and disposal.*
- *It ensures a higher level of quality: components and services are installed at works to a constant quality level and with comprehensive quality controls; and risk of accidents on site is reduced.*
- *It is environmentally friendly: building sites are cleaners; waste products are avoided on site; and the reuse of components is simplified by the scope provided for a damage-free dismantling and removal of elements".*

"An important aspect of this system is the absolutely damage-free process once the building has served its useful life. Components or entire buildings can be reused or returned to the manufacturer for recycling – an important aspect when one considers that the building industry holds the record at present for the creation of waste and the consumption of raw materials."

References

Books

- Prefabricated Modules in Construction, R. Neale, A. Price and W. Sher, The Chartered Institute of Building, 1993.
- DETAIL, Prefabrication.

Journals

- "Room Service", J. Osborn, article in Building 29 June 1984.
- "The Domain of the Ready-made", A. Stewart, article in Building 28 November 1986.
- "All Live in Little Boxes?", article in Design 480 December 1988.
- Innovative Plug-in Connections – The Key Technology for Prefabricated Housing, Prochiner F., Walczyk R., Hartmann D., Detail Magazine 4, 2001.
- Different Forms of Construction for a Modular Unit Building System, Sahner G., Detail Magazine 4, 2001.
- Moving Construction Offsite – Modular Construction, Peter Moore, Structural Symposium May 2001, Environmentally Friendly Structures, Hong Kong.

Other references

Inside

- Refer to chapter 4.3.1 on Dimensional Coordination (some references).
- Refer to chapter 6.2 on "Off site: Precast and Prefabrication".
- Refer to chapter 5.2 "Material Selection".
- Refer to case study on Integer pavilion.

Top: Metal formworks. Middle: left, timber waste from formworks, right, metal temporary work. Bottom: left, reusable platform formwork, right, metal platform work.

4.3.3. Minimizing temporary works

Temporary works generate waste on site, and therefore their use can be minimized by alternative forms of design and construction methods. They can also be reused on other sites or recycled to minimize waste generation. According to a survey conducted by the Department of Civil and Structural Engineering, of the Hong Kong Polytechnic University, in 2001, 54% of the respondents (mainly architects and structural engineers), have considered alternative forms of design to reduce the need for temporary works.

Objectives

- **Minimize temporary works and extend their lifespan to reduce waste.**
- **Allow the use of reusable or recyclable components.**

Waste Type

Waste arising from temporary works:

- Bamboo from bamboo scaffoldings.
- Timber from timber hoarding…

Strategies

- Consider how the design is constructed to minimize temporary works.
- Consider alternative forms of design to reduce temporary works.
- Check with contractor or experienced constructors the construction methods and materials that can reduce temporary works.
- Choose temporary work materials that can be reused on other sites such as metal hoarding, metal scaffolding… (Bamboo scaffoldings may be more environmentally friendly options).
- Consider the use of high-quality temporary components that can be reused and last longer.
- Allow the use of prefabrication or modularization to minimize on site works that produce waste.

Benefits

Cost

- Benefits can occur if temporary works are reused on the same site and other sites.

Environment

- It reduces waste landfilled.
- It extends landfill life span.
- Less pollution created by transportation of waste to landfill, and less energy used and less noise.

Regulation & Standards

Practice Notes for Authorised Person:

- PNAP 243- Construction and Demolition Waste.
- PNAP 153- Tropical Hardwood Timber.

Technical Circulars from Works Bureau:

- No.19/00: Metallic Site Hoardings and Signboards.

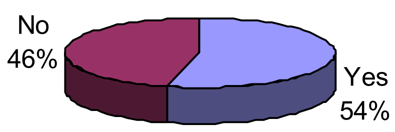


Figure 18: Consideration of alternative forms of design to reduce the need of temporary works. (Source: Hong Kong Polytechnic University survey, 2001)

Top: Metal scaffolding. Bottom: Mixed bamboo and metal scaffolding.

References

Books

- A Guide for Managing and Minimizing Building and Demolition Waste, C.S. Poon, T.W. Yu and L.H. Ng, the Hong Kong Polytechnic University, May 2001.

Reports

- CIRIA Special Publication 134, Waste Minimization and Recycling in Construction – Design Manual (1999).
- CIRIA Special Publication 133 Waste Minimization and Recycling in Construction – Site Guide (1997).
- CIRIA Special Publication 135 Waste Minimization and Recycling in Construction – Boardroom Handbook (1999).
- CIRIA Special Publication 122 Waste Minimization and Recycling in Construction – A Review (1995).

Web sites

- Low Waste Building Technologies
http://www.cse.polyu.edu.hk/~cecspoon/lwbt

Other references

Inside

- Refer to chapter 6 "Construction Method Selection to Minimize Waste".
- For case studies, refer to the low waste building technologies web site.

Reusable safety system

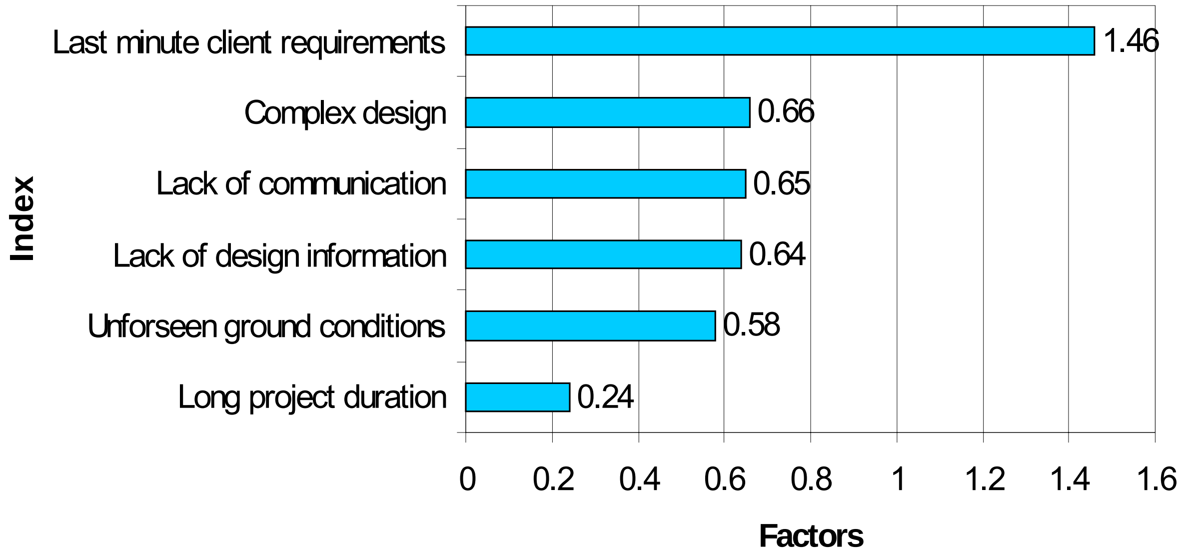


Figure 19: Causes of design variations (Source: Hong Kong Polytechnic University Survey, 2001)

Waste arising from redoing works.

4.3.4. Avoid late design modifications

Design modifications can generate an enormous quantity of waste if they occur when the building is almost constructed. Therefore design modifications should be considered early at the design stage.

According to a survey conducted by the Department of Civil and Structural Engineering, of the Hong Kong Polytechnic University, in 2001, the causes of design modifications are "last minute client requirements, complex design, lack of communication, lack of design information…"

Objectives

- **Avoid late design modifications that can generate waste at the construction stage.**

Waste Type

Waste generated at the construction stage by design modifications such as:

- Constructed structural elements.
- Constructed finishes.
- Materials that have already been ordered and cannot be reused on other sites.

Strategies

- Consider in advance (at the design stage) the modifications that can occur at the construction stage.
- Allow for flexibility in the design and construction process to allow changes.
- Avoid last minute client requirements by arising the client's attention on the problems, and preparing detailed drawings and specifications at an early stage (today's software can help on clarifying project understanding and presentation, 3D images and animations, 3D simulations…).
- Avoid lack of communication between designers, contractors, engineers and clients.
- Avoid lack of design information.
- Avoid complex designs that can generate errors and abortive works.

Benefits

Cost

- Late modifications in the design can be expensive because of the constructed elements and materials ordered. Allowing early modifications at the design stage can save money and time.

Environment

- It reduces waste disposed to at landfills.
- It extends the life span of landfills.
- Less pollution created by transportation of waste to landfill, and less energy used and less noise.

Others

- It can save time in construction by avoiding to redo works.

References

Books

- Waste Minimization and Recycling in Construction, Design Manual, CIRIA Special Publication 134, 1999.

4.3.5. Detailing design

Detailing design can minimize waste generation arising from construction (errors in construction) and from demolition (providing reuse and recycling possibilities).
According to a survey conducted by the Department of Civil and Structural Engineering, of the Hong Kong Polytechnic University, in 2001, 69% of the respondents agreed that providing better detailed designs would minimize waste generation during construction.
A detailed design must consider buildability as an important factor.

Objectives

- **Consider detailed designs to avoid the generation of waste during construction and demolition.**

Waste Type

Types of waste generated by errors due to insufficient details in design:

- Concrete.
- Reinforcement bars in concrete.
- All types of waste.

Strategies

- When designing, consider detailing and buildability at the same time. "Waste generated at the construction stage can be caused by lack of design detailing referring to buildability… A better understanding of the constructability can avoid errors at construction through better detailing of the design" (D. R. Moore, Development of Skill Models as an Aid to Buildability in Design, De Montfort University Leicester, UK).
- Consider detailing and buidability when dealing with prefabrication (details planned in advance).
- Avoid lack of detailing that causes construction errors, poor on-site performance, late completion and poor product quality.
- Consider experienced knowledge of professionals to help on proper detailed designs.

Definition of buildability (Illingworth):
"… The design and detailing which recognize the problems of the assembly process in achieving the desired result safely and at least cost to the client."

- Detailing is also related to durability design. "Form and detailing of structures and quality of materials which determine the reliability of structures", J.G.M. Wood, Durability Design: Form, Detailing and Materials.

Benefits

Cost

- Optimized building lives via detailed designs, benefits can be appreciated.

Environment

- It avoids waste generated by errors in construction and/or material failure.
- It reduces waste disposed to landfills.
- It extends the life span of landfills.
- Less pollution created by transportation of waste to landfill, and less energy used and less noise.

Others

- It can optimize building lives.

References

Books

- Building the Future, Innovation in Design, Materials and Construction, 1993, it includes:
- Development of Skill Models as an Aid to Buildability in Design, DR Moore, De Montfort University Leicester, UK.
- Durability Design: Form, Detailing and Materials, JGM Wood, Structural Studies & Design Ltd, UK.

Other references

Inside

- Refer to chapter 4.2.1 "Optimizing design lives".
- Refer to chapter 5 "Material selection to minimize waste".

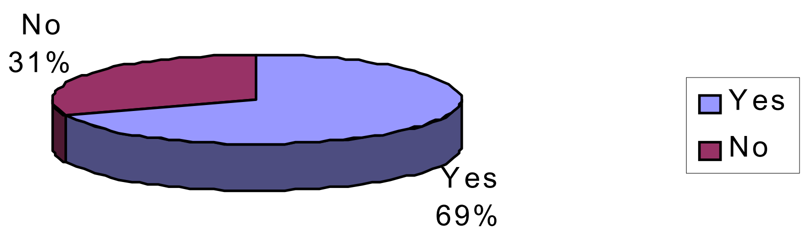


Figure20: Respondents agreeing that providing a more detailed design will minimize waste generation during construction. (Source: Hong Kong Polytechnic University Survey, 2001)