THE UNIVERSITY OF HONG KONG

MAINTAINABILITY INDEX FOR BUILDINGS:

A MODEL FOR BUILDING MAINTAINABILITY

ASSESSMENT IN HONG KONG

A DISSERTATION SUBMITTED TO

FACULTY OF ARCHITECTURE

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BY

LAU WAI KIN

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Declaration

I declare that this dissertation represents my own work, except where due acknowledgement is made, and that it has not been previously included in a thesis, dissertation or report submitted to this University or to any other institution for a degree, diploma or other qualifications.

Signed: ____________________

Name: ____________________

Date: ____________________

‘When we build, let us think that we build forever.’

- Ruskin, 1849, *The Seven Lamps of Architecture*

‘We give shape to our buildings; thereafter they shape us.’

- Churchill, 1943, a speech to the House of Commons

‘Vision without action is a daydream.

Action without vision is a nightmare.’

- Japanese proverb

‘April is the cruelest month.’

- T. S. Eliot, The Waste Land (1922)

Abstract

Buildings in Hong Kong, in particular, private housings are ageing at a rapid pace over the past few decades. Maintenance will ultimately become more demanding in the near future together with the tabled Mandatory Building Inspection Scheme. It is high time to rethink the current practice where building for maintenance is largely neglected during the development process. Incorporating the concept of maintainability into building designs and daily management can yield benefits in many aspects including cost, safety and building performance. The purpose of this study is to develop a Building Maintainability Assessment Model to quantify the abstract notion of maintainability in the local building industry.

This study first reviews the concept of building maintenance and maintainability, meanwhile, particular account in local industry is given. Factors affecting the maintainability of building in design, planning and management aspects are identified to formulate the survey questions. Through 13 structured interviews with very experienced property managers and maintenance managers who hold key positions in both public and private sector in early 2008, importance of these factors are ranked and weighted. Feedbacks from interviewees are gathering to refine the assessment mechanism. Insights are gained extra into maintenance issues in Hong Kong.

Contrast to past studies which leaned towards maintainability of building designs, the significance of various pre and post-occupancy practices which are unrelated to design aspect are underlined. The performance of Building Services Systems in maintainability closely connects to the overall maintainability too. Two sets of assessment mechanism is put forward and explained. In response to the feedbacks from the interviewees, the module for assessing maintainability of construction systems is obviated in one of the aforementioned assessment mechanisms. The principles underpinning the choices are explained with selected issues on maintenance reported. In the absence of research in the subject of maintainability in buildings, there is ample scope for Hong Kong to consider the voluntary use of the model as a yardstick to assess existing buildings and seek possible rooms for improving maintainability through managerial approaches, whilst for new buildings preliminary assessment can be done through desktop surveys to evaluate design schemes from maintainability perspective and look for solutions which facilitate future maintenance. Furthermore, the key points identified may serve as maintainability guidelines for designers and property managers.

(372 Words)

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CHAPTER 5 – DEVELOPMENT OF THE MAINTAINABILITY ASSESSMENT MODEL AND ITS ASSESSMENT MECHANISM

LIST OF ABBREVIATIONS

British Standard Institute	BSI
Building Authority, HKSARG	BA
Building and Construction Authority, Singapore	BD
Buildings Department, HKSARG	BCA
Building Management Ordinance, HK Laws	BMO
Building Management System	BMS
Communal Aerial Broadcasting Distribution System	CABD
Condition Based Maintenance	CBM
Deed of Mutual Covenant	DMC
Defects Liability Period	DLP
Democratic Alliance for the Betterment and Progress of Hong Kong	DAB
Design and Build	D & B
Gross Domestic Product	GDP
Gross Floor Area	GFA
Total Gross Value of Construction	GVC
Total Gross Value of Maintenance Work Done	GVM
Hong Kong Special Administrative Government	HKSARG
Housing, Planning and Lands Bureau, HKSARG	HPLB
Mandatory Building Inspection Scheme	MIBS
Ministry of Manpower	MOM
National University of Singapore	NUS
Owners' Corporation	OC
Total Service Income of Real Estate Maintenance Management	REMM
Sick Building Syndrome	SBS
Saleable Floor Area	SFA
Standard Method of Measurement of Building Works	SMM7
Unauthorized Building Work	UBW

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CHAPTER 1 INTRODUCTION

1.1 Background of the Study

Right before the millennium, the importance of enhancing building maintainability has caught sight of policy makers in Singapore to help attaining greater productivity and other breakthroughs in the building industry. In its report, CTC (1999) commented that it was indisputable to view all project stages in totality to achieve great efficiency throughout the whole lifecycle of the project. In the meantime, the establishment of a maintainability scoring system to grade buildings accordingly was strongly proposed. This result in subsequent research initiated by the National University of Singapore (NUS) and the Building Construction Authority (BCA) in Singapore focusing on maintenance issues of buildings under tropical buildings (Chew *et al*., 2004).

While on the contrary, the significance of maintainability of building in Hong Kong is not greatly appreciated though Singapore and Hong Kong both look much alike in many aspects. The local construction industry was first called attention to the subject in the Report of the Construction Industry Review Committee (CIRC, 2001). With an ambition to improve the life long performance of buildings and the environmental performance of the industry, it is advised that more maintainable buildings should be promoted.

The concept of maintainability of building principally stresses on ease and effectiveness of maintenance, which encompasses elements in planning, design and management of facilities to optimize the maintenance process. With less resource the same or even better outcome can still be given. This property is essential to deal with the soaring maintenance costs which are confronted by building owners (Bourke and Davies, 1997; Cash, 1997a, b; Horner *et al.*, 1997; Cane at al., 1998; Van Widen and Dekker, 1998; Underwood and Alshawi, 1999; Shohet *et al.*, 2002). There is, however, far more benefits in addition to saving maintenance costs, such as enhanced building performance and better work place safety of the management personnel.

Considering three issues in Hong Kong namely the ageing trend of buildings, the tabled Mandatory Building Inspection Scheme (MBIS) and the lofty cost in maintenance, the importance of building maintainability which enables maintenance tasks to be carried out with ease should be highlighted. As far as the ageing problem of buildings is concerned, definitely, the need for maintaining old buildings will become greater sometime (Chan, 2004; Leung and Yiu, 2004; Yiu, 2007b) (Figure 1.1 and Table 1.1) [1 and 2]. Moreover, government intervention in building maintenance through the proposed MBIS which requires buildings to be inspected periodically and then repair will at the same time ask for more maintenance occasions. For the sake of facilitating maintenance tasks so as to cut maintenance costs, improving post-occupancy building performance as well as creating a better built-environment in the time when more frequent maintenance activities are expected, the concept of maintainability of building should be emphasized and administered in planning, designing and managing a building.

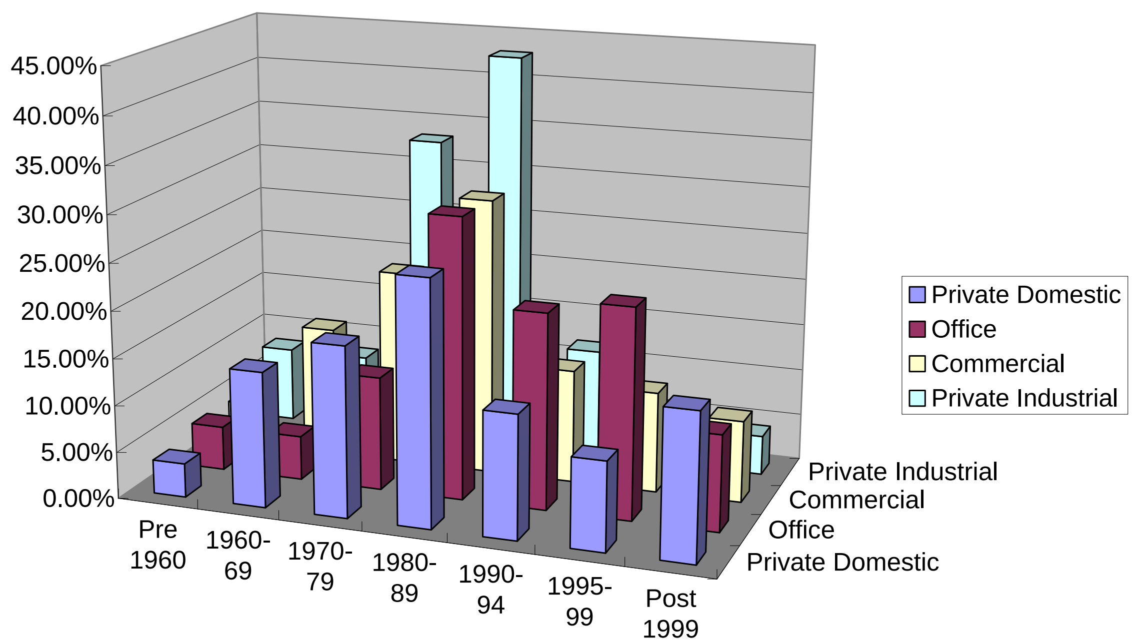

Figure 1.1 Distribution of the Building Age of Buildings in Hong Kong (source: extracted from the Hong Kong Property Review, 1998-2007, Rating and Valuation Department, HKSARG)

[1] From the data, it is obvious that buildings built before 1989 dominate the building stocks in Hong Kong, this implies that by 2010 buildings in Hong Kong will mostly with age over 20 years, or more accurately, 30 years. More frequent maintenance are foreseen.
[2] The problem of ageing building is also observed in many other countries such as Singapore (Figure 1.2) and Australia

Building Type	With age over 20 years
Private Domestic	62%
Office	47%
Commercial	69%
Private Industrial	84%

Table 1.1 Percentage of building stocks with age over 20 years by building type (source: extracted from the Hong Kong Property Review, 1998-2007, Rating and Valuation Department, HKSARG)

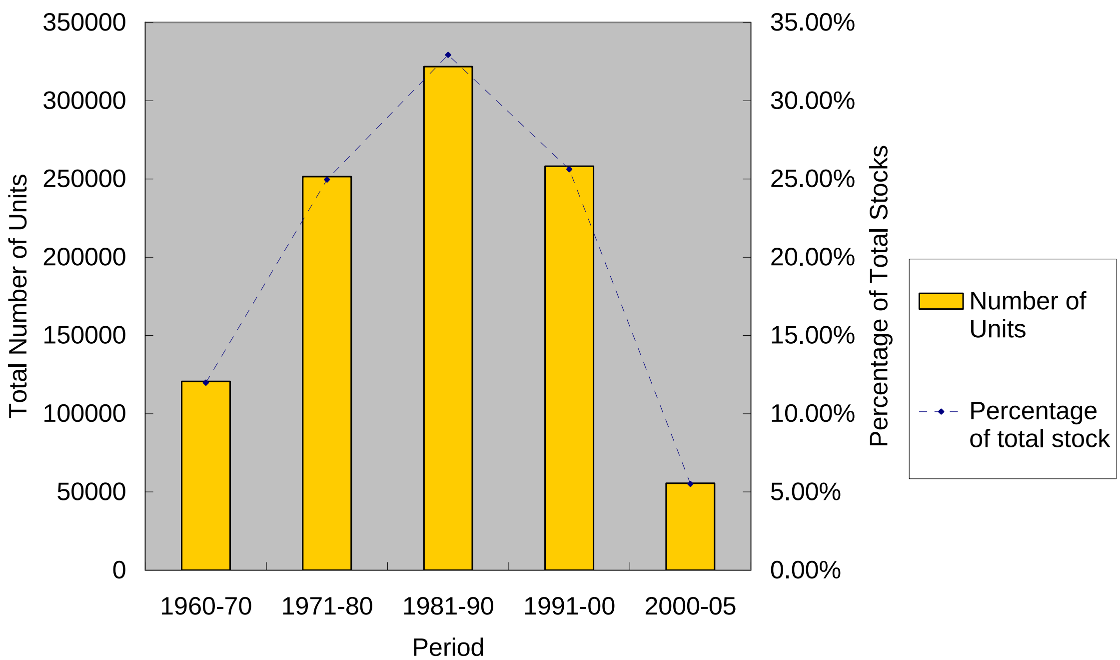

Figure 1.2 Building Age Distribution of Dwelling Units and Commercial Developments of Housing and Development Board, Singapore (source: Statistics Singapore, 2007) (* total number of units equals to nos. of dwelling units and commercial developments by HUD)

The gist of the above contentions all prompt in placing emphasis on the maintainability of building in Hong Kong. Hence, concrete measures to improve building maintainability in the local context should be proposed. It is therefore hope that establishing a mechanism which enables involving parties throughout the whole life cycle of buildings to evaluate and check their decisions concerning building maintainability objectively and accurately to evaluate the maintainability of buildings can take the first step. Due to the fact that variances are present in the construction industry practices and the climatic conditions in Hong Kong and Singapore, a different set of assessment mechanism is established. Having assessed buildings using this model, appropriate actions can be taken to rectify any deficiencies in maintenance in any event.

With to regard to this research, as the ultimate goal is to develop benchmarks of maintainability for different types , various aspects in planning, design and management contributing to building maintainability will be studied and these research findings are employed to form the Maintainability Assessment Model afterwards.

1.2 Aims and Objectives of the Study

To sum up, the objectives of this study are:

1) To identify factors and elements in design, planning and management aspects that affect the maintainability of building;

2) To construct a framework for assessing the maintainability of building;

3) To find out the relative importance and weightings of the aforesaid factors and elements in respect of maintainability through structured interviews;

4) Founding on 1) and 3), to devise stratagems from the identified essentials to improve building maintainability; and

5) With 1) to 3) as underpinnings, to develop an assessment model with detailed explanation to its assessment mechanism

1.3 Significance of the Study

Unlike most engineering related disciplines such as software engineering, the paradise of maintainability of building remains largely unopened though the importance of maintainability of buildings to achieve cost savings and the better functioning of facilities have been highlighted theoretically (Briffett, 1990; Chew, 1994, 1999; Assaf *et al.*, 1995; Blanchard *et al.*, 1995; Shen *et al.*, 1998; Arditi and Nawakorawit, 1999a, b; Dunston and Williamson, 1999). On that account, this study contributes to this body of knowledge in two ways; first, to keep on exploring the features and measures attribute to building maintainability, whilst the second is to develop an assessment model to quantify the abstract notion of maintainability for appraising the maintainability of buildings from planning, design and managerial aspects.

Evaluating building maintainability quantitatively is in particular useful to decision makers – designers and the project team can utilize the model for assessing building performance from maintainability perspective in determining the design and construction options. Property manager can identify the strengths and weaknesses of a building in terms of maintenance and take appropriate actions to facilitate the maintenance works. To a lesser extent, property investor can be more definite about their financial position because maintainability can be acted as an indirect indicator of occupancy cost. In general maintainable buildings require less resource and effort in maintenance. Stakeholders can be benefited in long term by saving time and costs in maintenance, whereas such benefit is remarkable in view of the fact that the MBIS is going to be implemented in the near future. Moreover, organizations with a large stock of real assets such as the Housing Authority whose cost burden on maintenance can be relieved gradually with more maintainable features incorporated into their facilities.

1.4 Organisation of the study

This dissertation consists of 6 chapters which can be further divided into 3 parts namely:

Part 1: Introduction (Chapter 1)

Part 2: Literature Review (Chapter 2)

Part 3: Research and Development of the Assessment Model (Chapter 3-6)

Chapter 1 Introduction

This chapter introduces the background behind which the study is initiated. The objectives to be attained and the significance of the study are stated as well, meanwhile, the structure of the dissertation is outlined.

Chapter 2 Literature Review

A comprehensive literature review on building maintenance and building maintainability is provided in this chapter. In gist, the theoretical framework is established through reviewing studies in building maintainability supplemented by those with focal points in various issues in building maintenance, such as local maintenance problems.

Chapter 3 Methodology

In this chapter, a detailed discussion of the methodology is given. The way of executing the research, which is in principal through structured interviews with very experienced practitioners in property management and building maintenance, are explained in detail. On the other hand, the logic behind are accounted for the relevance to the study.

Chapter 4 Data Analysis and Discussion

The quantitative and qualitative data collected is analyzed prior to discussion on the subject. The quantitative data, that is, results from the questionnaire survey are computed to work out the relatively importance indices for developing the assessment model. Beside, views from respondents on the subject of building maintenance and maintainability are reported. In the following, discussion on the findings from the analyzed data is made.

Chapter 5 Development of the Maintainability Assessment Model and its assessment mechanism

With both the quantitative and qualitative data obtained from the structured interviews, the assessment model can be developed and subsequently the assessment mechanism of the model is explained in depth.

Chapter 6 Conclusion

The conclusion of this dissertation is dedicated to this chapter to sum up the study. Thus, the summarized findings and the outcomes are reported. Moreover, limitations of the study and further research area to be explored are presented.

In the next chapter, a comprehensive literature review of building maintenance and building maintainability will be given.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

To retrace the concept of 'Maintainability', the US Military Services was the first who put forward it formally in 1954 to deal with the soaring costs and manpower engaged in maintenance (Blanchard and Lowery, 1969). Traditionally, maintenance was regarded as the Cinderella of the building industry – always overlooked and least favoured (Seeley, 1987; Lee and Yuen, 1993; Mytton-Davies, 2001; Wise and Swaffield, 2002; Macdonald, 2003; Wood, 2003). It was not until 21 years later the concept of maintainability was incorporated into building designs to facilitate future maintenance. Such movement was brought about by Fledman (1975) who intended to make changes in the design of buildings from the standpoint of ease of maintenance to offset the soaring maintenance costs and the difficulty of finding and training maintenance personnel anticipated in a super-technological future.

In academia but not in practice, the benefits associated with maintainability of buildings in saving maintenance costs and achieving better function of facilities have been realized by researchers since then (Briffett, 1990; Chew, 1994, 1999; Assaf *et al*., 1995; Blanchard *et al.*, 1995; Shen *et al.*, 1998; Arditi and Nawakorawit, 1999b; Dunston and Williamson, 1999). Neither maintenance nor maintainability is at the top of building professionals when they practice (CTC, 1999; Chew and De Silva, 2003). Building designers, for example, ranked maintenance after design quality, building user comfort and safety when they consider the design of buildings (Arditi and Nawakorawit, 1999a).

In the following literature review, it consists of two parts focusing on building maintenance and building maintainability. Selected issues in building maintenance are reviewed first of all. Definition and types of maintenance are looked at to establish the framework of the forthcoming study. If the requirements for maintenance were absent, why owners bother to maintenance their properties? In this connection, the needs to maintain are highlighted in physical, economical and legal aspects. To understand the reason why maintainability of buildings is necessary to facilitate and help maintenance, problems associated with building maintenance are identified. Particular account in local context is given. Having probed into building maintenance, the subject of maintainability of building is reviewed afterwards with extensive discussion on the work of researchers worldwide. Findings from this chapter serve as the foundation and provide helpful information for the research design and establishing the assessment framework.

2.2 What is Building Maintenance?

Before progressing, the term 'maintenance' should be defined above all. As defined by the British Standard Institute in BS 3811 (BSI, 1993; Allan, 1993), it refers to 'the combination of all technical and administrative actions, including supervision actions, intended to retain an item, or restore it to a state in which it can perform a required function.' It is, however, a generic one and do not specifically confine to building maintenance. HMSO (1972) provided a definition in building context as 'work undertaken in order to keep, restore or improve every facility, i.e. every part of a building, its services and surrounds, to a currently accepted standard and to sustain the utility and value of the facility.' On account of various maintenance tasks, except domestic but daily and routine cleanings should be treated as one of the maintenance activities as well (Seeley, 1987), despite presence of opposite views in BS 8210 (BSI, 1986).

Keeping in view that the living standard and expectations from occupiers are rising, BSI's definition is not precise to describe building maintenance without the elements of improvement (BSI, 1986, 1993). In BS 8210:1986 Guide to Building Maintenance Management, "improvements, additions or alterations" are excluded explicitly from the scope of building maintenance management. Generally speaking, reasonable improvement works would be introduced rather than retaining. Only on rare occasion replacements will be exactly the same as the original, which may be superior in some respects and vice versa, inferior in others (Wordsworth, 2001). Similarly, Chanter (1996) holds the view that maintenance works are to reinstate efficient performance of building functions as designated. Some upgrading may be included to raise the original standards to contemporary one and rectify design faults where necessary.

Legally, similar viewpoint is observed in recent years. In *Bayview Mansion v Chan Cheung Kit Mui Margaret*[3], the court held that renovation works (i.e. improvement) are distinct from maintenance works, where the former could not be described as keeping the common parts in a state of good and serviceable condition, nonetheless, amendments were made in 1998 to the Building Management Ordinance[4] to empower the Owner's Corporation to "renovate, improve and decorate the common parts of their buildings" rather then just to "maintain".

On balance, building maintenance is denoted as any measures taken to keep, restore or improve building facilities without extensive alternation or improvement (i.e. change of building use) to contemporary standard to achieve the designated maintenance objectives.

Looking building maintenance from another perspective it is actually the means to achieve various objectives set by the owners. Different building types or uses are definitely subject to different maintenance objectives, for example, strict security services are demanded in Grade A offices. In general, the objectives of building maintenance can be outlined as follows (Alner and Fellows, 1990):

- to ensure that the buildings and their associated services are in a safe condition;
- to ensure that the buildings are fit for use;
- to ensure that the condition of the building meets all statutory requirements;
- to carry out the maintenance work necessary to maintain the value of the physical assets of the building stock; and
- to carry out the work necessary to maintain the quality of building.

[3] [1995] (HKLD 125)
[4] HK Laws Cap. 344

2.3 Building Maintenance Management and Types of Maintenance

Under most circumstances several strategic options are available to management in maintaining a building (Horner *et al.*, 1997). Building maintenance management is therefore the organization of resources which dedicate to maintenance within an agreed policy (BSI, 1993; Lee and Yuen, 1993). In addition to budgetary constraints, it involves decision-making under multiple objectives and uncertainty (Lounis and Vanier, 2000). Accompanied by a good maintenance policy which defines the management philosophy, the goal and the corresponding strategy to achieve it, effective maintenance management targets at the following four objectives (Lo and Wong, 1998):

1) reliability of the operation;
2) recovery after breakdown;
3) customer focus service; and
4) total quality of the process.

In their paper, Lo and Wong further suggested defining parameters relating to quality, time and cost in formulating the policy (Table 2.1). These elements establish the framework within which maintenance management system (Figure 2.1) is detailed and subsequently be realized in various aspects (Figure 2.2). Thus, maintenance policies may be regarded as the core in maintenance management.

Dimension	Details
Cost	• The budget available for maintenance and the likely sources of finance
Quality	• The standards to which the building and its facilities should be maintained
Time	• The life expectancy of the building and its ancillary facilities, such as fittings and services • The response time required

Table 2.1 Dimensions to be defined in formulating the maintenance objective (source Lo and Wong, 1998)

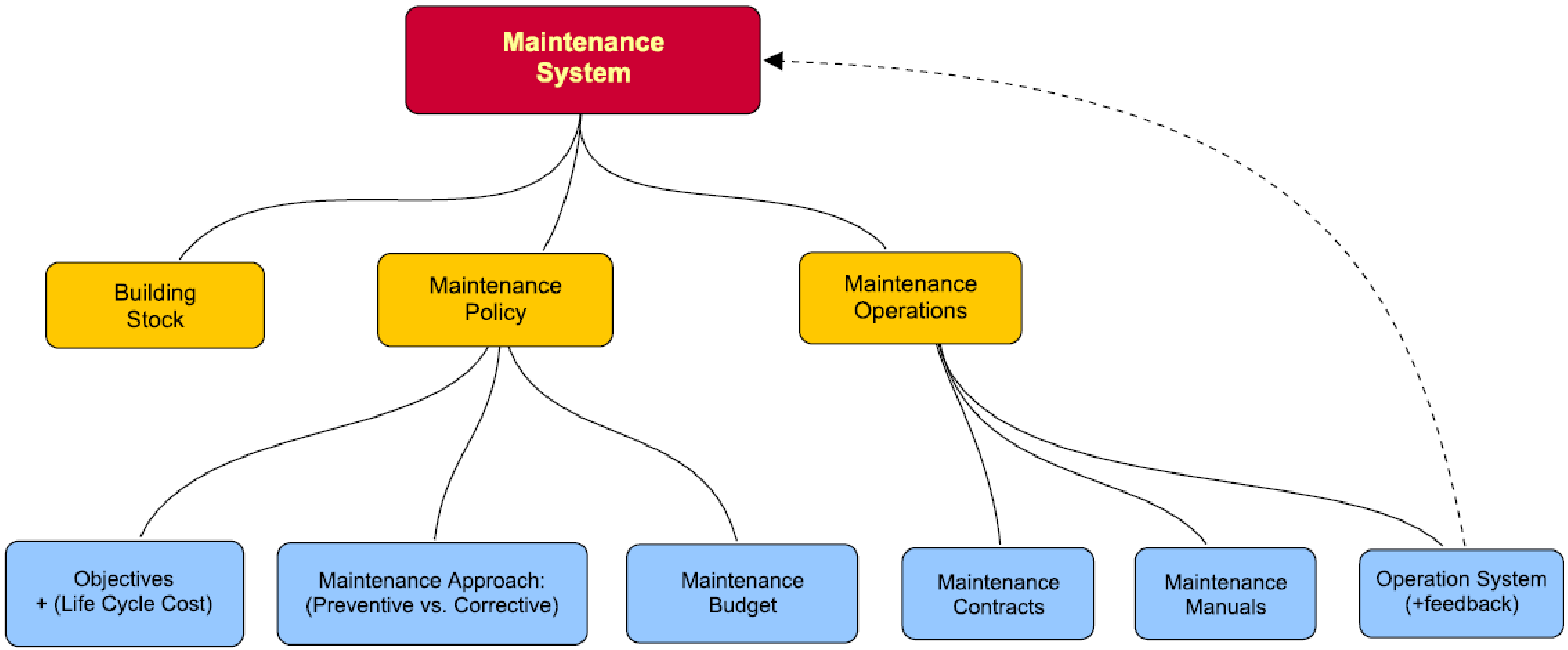

Figure 2.1 Overview of the Maintenance Management System (source: Yiu, 2007)

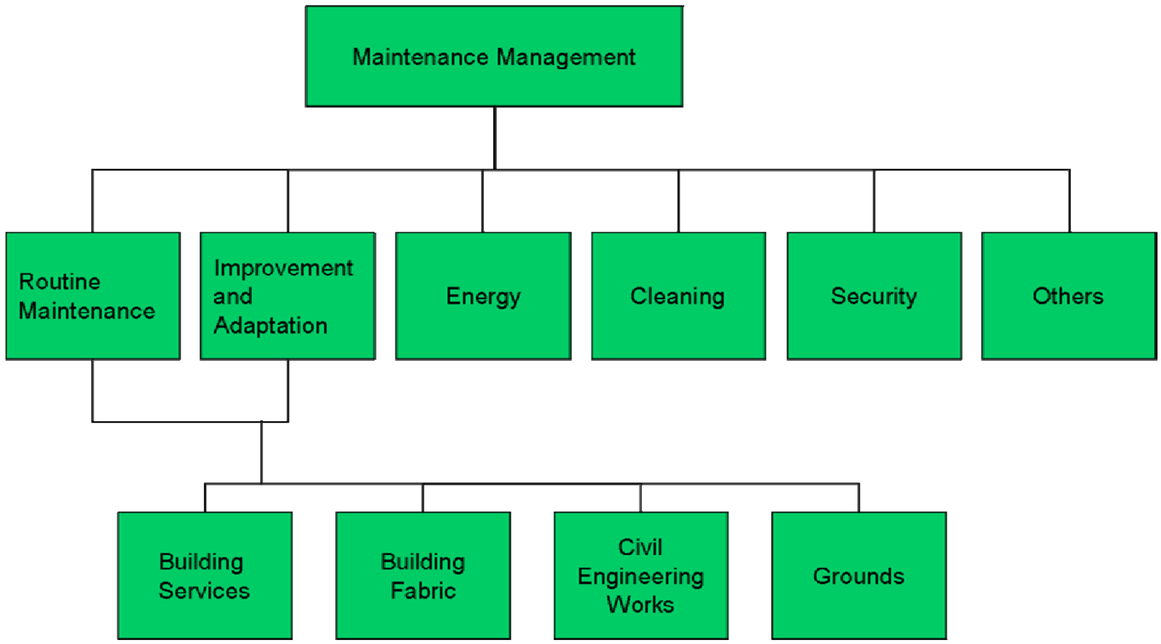

Figure 2.2 Aspects of maintenance management (source: Lee and Yuen, 1993)

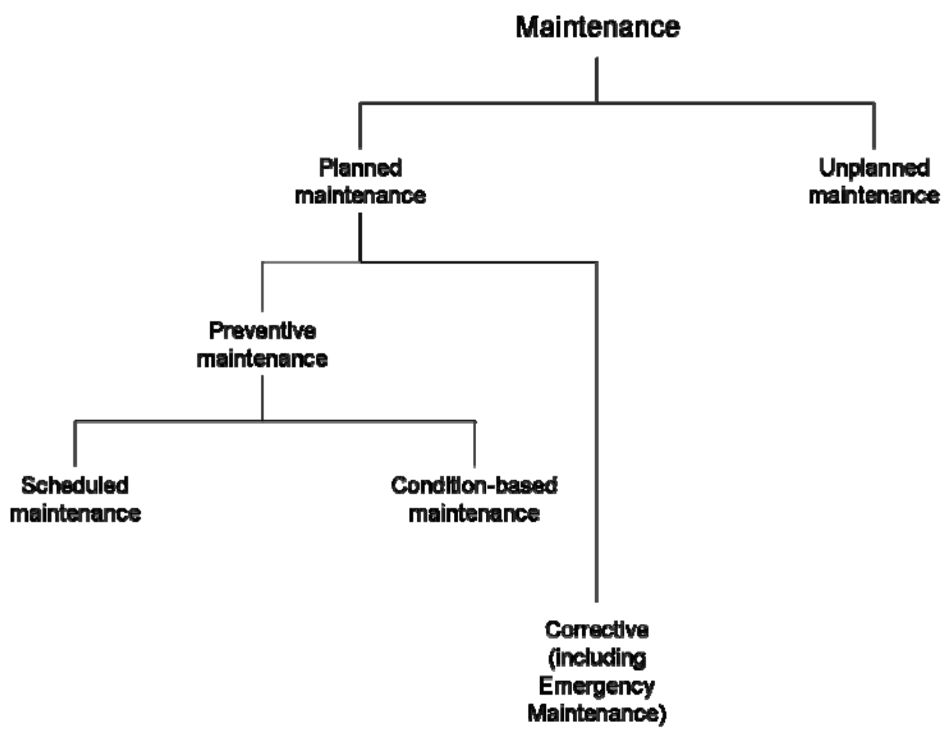

Figure 2.3 Types of maintenance (source: BS 3811: 1984)

Depending on the maintenance agenda, different strategic options, that is, maintenance types are adopted. BSI (1984) defined different types of maintenance and categorized them into ‘planned’ and ‘unplanned’ maintenance (Figure 2.3), whereas Speight adopted a slightly different approach which classified maintenance based on the nature and occurrence. Under such classification, maintenance is subdivided into three broad categories including major repair or restoration, periodic maintenance and routine or day-to-day maintenance (Mills, 1980). Details of this classification are given in Table 2.2. Corrective maintenance, preventive maintenance and condition-based maintenance in the former classification are discussed in the following.

Category	Examples
Major repair or restoration	Re-roofing or rebuilding defective walls,
Periodic maintenance	Annual contracts for decorations and the like
Routine or day-to-day maintenance (Preventive)	Checking rainwater gutters and servicing mechanical and electrical installations

Table 2.2 Maintenance classification adopted by Speight (source: Mills, 1980)

Corrective Maintenance

Corrective maintenance, or repair, is the simplest maintenance strategy such that no maintenance is ongoing until an element in building breaks down resulting in interruption of service. Its primary objective is to resume the required functioning of the failed item and thus, repairs and replacement are always involved (BSI, 1984; Kyle *et al.*, 2000; Galaty *et al.*, 2003) (Figure 2.4); and further, it may distinguish into two class according to nature of failure, that is, emergency and normal response (Askworth and Hogg, 2007). Because of the unplanned nature, corrective maintenance is considered as failure-based and its tasks often take place in an ad hoc manner (David and Arthur, 1989). Despite less frequent occurrence, corrective maintenance is blamed for its lofty costs and experienced based nature of work which is less safe and reliable (Horner *et al.*, 1997; Li, 1999).

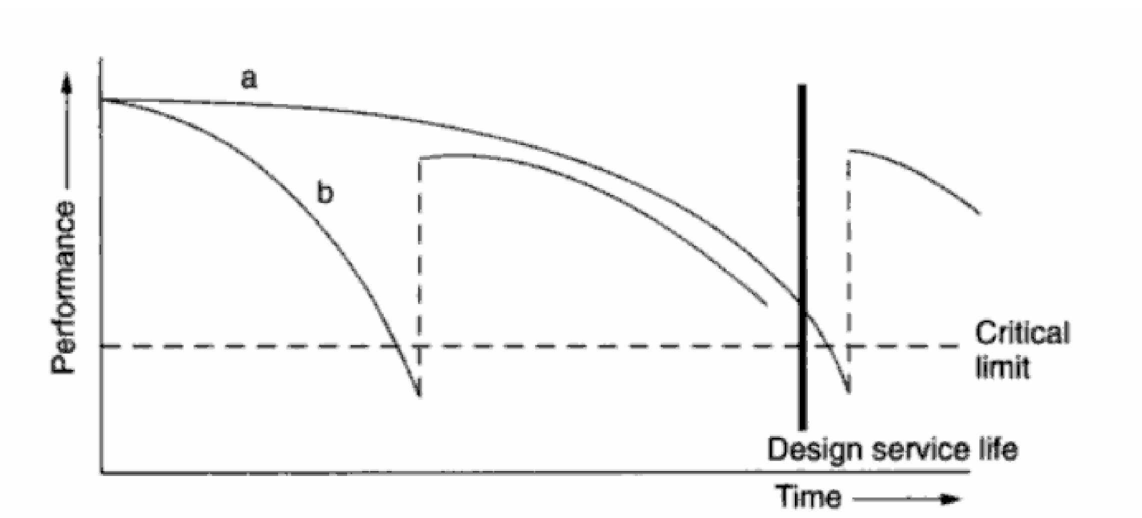

Figure 2.4 Performance of building material, building component or structure in time: a) no corrective or preventive maintenance required, no damage b) corrective maintenance was necessary, damage (source: Bijen, 2003)

Preventive Maintenance

Not alike corrective maintenance, preventive maintenance is planned in accordance with the prescribed policy with a goal to reduce the chance of performance degradation, failure or sudden failure of items. It is believed that this maintenance type is more applicable to plants and equipments which are subject to frequent mechanical wear, however, certain building elements may still justify this treatment (BSI, 1984; Horner *et al.*, 1997; Wordsworth, 2001).

Preventive maintenance may be further identified as prescribed, reactive and inspective according to their respective scope of work (Bijen, 2003). To implement preventive maintenance, it is necessary to prepare an inventory of all facilities in a building that require maintenance in the first instance and determine their respective frequency of maintenance. Thanks to evolution of expert systems, this highly subjective determination process that rests on individual experience can be replaced and yield accurate results which consistent with past maintenance records (Culp, 1989; So *et al.*, 1999). Maintenance cycles are recommended too to improve reliability of building facilities (Table 2.3). Besides, researchers have attempted to identified factors for planned maintenance prioritization (Holmes and Shen, 1994; Spedding *et al.*, 1995 ; Shen *et al.*, 1998) (Figure 2.5 and Figure 2.6).

Facility	Item of Work	Cycle
External Walls	• Redecoration	5-6 years
Internal Walls	• Redecoration/ touching up	3 years
Fresh Water Supply	• Inspect, grease, switch pumps & check valves • Cleanse water tank & check valves	2 weeks 3 months
Flushing Water Supply	• Inspect, grease, switch pumps & check valves • Cleanse water tank & check valves	2 months 6 months
External Railings & Metalwork	• Inspect condition & refix • Repainting	1 month 6 months
Drainage – Roof Drainage - Underground	• Check and cleanse drains and surface channels • Check and cleanse manhole • T.V. survey	2 weeks 2 months 2 years
Lifts	• Oiling & servicing • Overhaul	1 week 1 year
Fire Services	• Inspect & refix by management staff • Overhaul & report to Fire Services Department • Smoke doors	1 week 1 year 1 – 2 days
Play Equipment	• Inspection by management staff • Inspection by mechanics	1 – 2 days 1 year
Slopes	• Inspect drainage by management staff • Inspection by Geotechnical Engineer	1 week 1 – 2 years
Others	• Alarms, Communal Aerial Broadcasting Distribution System (CABD), security, etc • Roofing, floors, finishes	6 months – 1 year 1 year

Table 2.3 Recommended maintenance cycles to improve reliability of building facilities in Hong Kong's case (source: Lo and Wong, 1998)

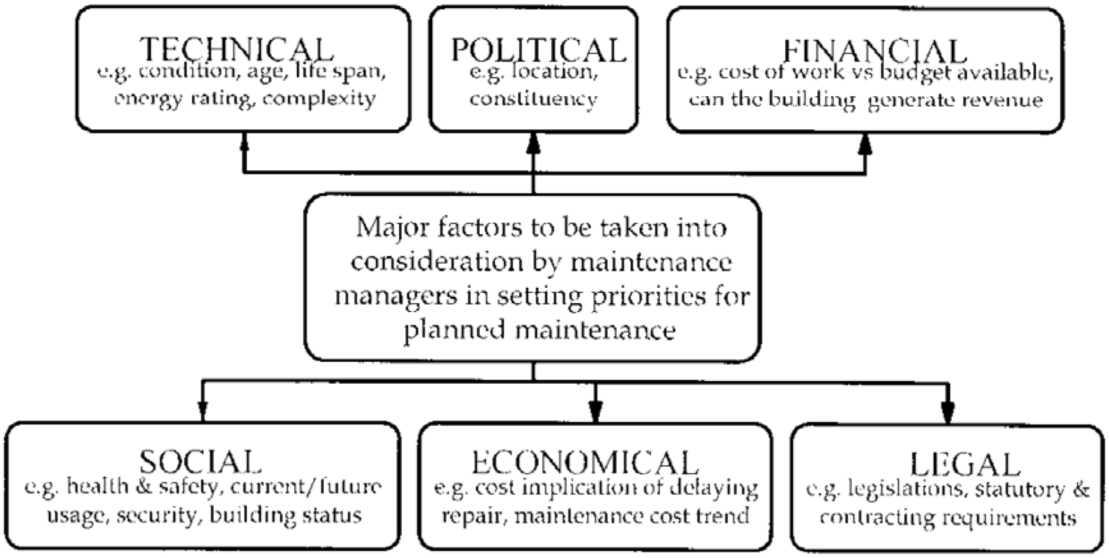

Figure 2.5 Major factors for planned maintenance prioritization (soruce: Spedding *et al.*, 1995)

It is evident that preventive maintenance is superior to corrective maintenance in achieving healthy building conditions (Woods, 1997), improving safety of the user, reducing maintenance cost by avoiding the cost of consequential damage, planning maintenance at users' convenience and minimizing downtime to increase the habitability of the building (Raymond and Joan, 1991). Nonetheless, the following limitations are highlighted and should be kept minimal (William, 1994; El-Haram, 1995):

- Carrying out unnecessary work or maintaining to an unnecessary high level
- Worsen the conditions of elements as a result of human error during execution of the maintenance task
- Demanding nature of preventive maintenance tasks in terms of spare parts and labour

Thus, evaluation should be conducted on the following aspects before proceeding to preventive maintenance (Bushell, 1979)

- Cost-effectiveness of preventive maintenance
- Needs to meet statutory or legal requirement
- Fulfillment of client's need from an operational perspective
- Possible reduction of maintenance works

EU (0.471) > PC (0.280) > BS (0.123) > EF (0.083) > IU (0.043)

Explanations:

1. *Building status* (BS). The relative importance of the building (where the defective element is examined) compared with others, in terms of function, current and intended future usage, e.g. an infant school might have a higher status than a leisure building.

2. *Physical condition* (PC). The physical condition of the defective element being examined, and its possibility of breakdown or failure, e.g. elements in very bad condition would be given higher priorities than those in fair condition.

3. *Importance of usage* (IU). The importance of the functional unit (in relation to other units within the same building) where the defects are situated, e.g., the reception area would be more important than storage rooms.

4. *Effects on users* (EU). The effects of breakdown or failure of the defective element(s) on the occupants and users of the building (including staff and members of the public), e.g., a problem relating to health and safety would be more important than an aesthetic problem.

5. *Effects on fabrics* (EF). The cost implication of breakdown or failure of the defected element(s) on maintaining the overall condition of the building fabric and building services, e.g., a defective roof would be given a high priority because if it is not repaired promptly the eventual cost will be higher due to possible damage to other building elements.

6. *Effects on service provision* (ESP). The cost implication of breakdown or failure of the defected element(s) for the provision of the services for which the building is used.

Figure 2.6 Prioritized six major criteria that identified as the most commonly used criteria in setting up maintenance priorities (source: Holmes and Shen, 1994; Shen *et al.*, 1998)

Condition-based Maintenance

Condition-based maintenance, or its abbreviation, CBM, is triggered by knowledge of a system or structure's condition from routine or continuous monitoring processes (BSI, 1984; Booty, 2006). Alternatively, Kelly and Harris (1978) defined it as 'maintenance carried out in response to a significant deterioration in a unit as indicated by a change in monitored parameter of the unit condition or performance'. Being another planned and preventive strategy, obviously, it relies largely on the constant monitoring process, for example, conditional surveys of building elements in planning and determining the optimal timing and scope of maintenance. Thus, to take the advantage of CBM, the monitoring process must be effective and accurate in determining the actual state of building components and quest for any changes from a normal to an abnormal condition. In this regard, the parameter which best reflects the actual condition of an item should be selected. Suitable monitoring tools should be used as well (Horner *et al.*, 1997).

2.4 Needs to Provide Maintenance

2.4.1 Physical Aspect: Against Deterioration and 'Sickness'

Building structures and human bodies are similar to each other to a certain extent as they both age with time naturally (Cheung, 2006); even so, old buildings do not necessarily pose a problem unless they have deteriorated due to lack of care and maintenance (Chan, 2004). Chan (2000) referred these problematic buildings as 'aged buildings' and these 'aged' buildings are often considered to have more problems in maintenance (Loo, 1991).

Most if not all buildings may start to deteriorate right after their completion (Baum, 1993). As such, the needs to provide proper and effective maintenance always exist to safeguard buildings against deterioration. Poorly maintained buildings are liable to structural and hygienic problems, which may eventually constitute hazards in health and safety (Haman and Bottcher, 1986[5]; Buildings Department, 1995[6], 1999[7]; Molloy, 1989[8]; Apter, *et al.*, 1994[9]; WHO, 1996[10]; Rosenstreich, *et al.* 1997[11]; Ng, 2003; Tilgner, 2003[12]; Leung and Yiu, 2004; Yiu *et al.*, 2004; Yiu, 2005[13]; FEHD, 2005[14]) (Table 2.4). Conversely, maintenance or even improvement works can be done to control, avoid or delay deterioration. The physical life of buildings may be extended through removing or minimizing all undesirable influence like building defects (Lee, 1987; Chew *et al.*, 2004). With proper management and adequate investment, it is believed that the performance of buildings can still be maintained despite ageing (Fong, 1984). In normal circumstances, however, rate of depreciation and influence on maintenance are connected with building age (Sweeney, 1973; Ohls, 1975; Arnott, *et al.* 1983; Holmes, 1985; Alner and Fellows, 1990; Somerville & Holmes, 2001; Hodgson, *et al.*, 2006). The needs to provide maintenance on physical aspect cannot be eliminated unless a hundred percent 'reliability' can be achieved (Blanchard and Lowery, 1969).

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[5] Haman and Bottcher (1986): Corrosion in plumbing system promotes the growth of pathogenic organisms and other undesirable problems such as discolouration of water

[6] Buildings Department (1995, 1999): Concerns on the effectiveness of repair on buildings – a low level of durability of the repaired parts

[7] Buildings Department (1999) : The deterioration developed behind the repair had been concealed by poor quality repairs or inappropriate repair methods

[8] Molloy (1989): Pest problems in buildings cause health problems as they can carry disease-bearing organism or contaminants

[9] Apter et al. (1994): certain syndrome such as headaches relates to Sick Building Syndrome (SBS)

[10] WHO (1996): Excreta must be disposed carefully or else it can be a channel to transmit disease

[11] Rosenstreich et al. (1997): Allergic reactions can be triggered by cockroaches and this is fatal to children with asthma

[12] Ng (2003) and Tilgner (2003): Cockroaches and rodents can help transmitting infectious material for their abilities as mechanical carriers

[13] Leung and Yiu (2004); Yiu et al. (2004) and Yiu (2005): Proliferation of Unauthorized Building Works has claimed at least 20 lives and 135 injuries in the decade from 1990 to 2001

[14] FEHD (2005): Certain mosquito pests can transmit diseases like dengue fever

Year	Collapses	Falling Objects	Fires	Others	Total
1990	4	0	0	0	4
1991	0	0	0	0	0
1992	3	0	0	0	3
1993	4	1	0	0	5
1994	4	2	1	1	8
1995	3	0	2	0	5
1996	9	6	1	0	16
1997	9	2	2	0	13
1998	5	0	5	0	10
1999	5	16	6	0	27
2000	14	14	5	0	33
2001 (up to 18/04/01)	11	7	1	0	19

Table 2.4 Accidents Related to Private Building Since 1990 (adapted from Leung and Yiu, 2004; source: Task Force on Building Safety and Preventive Maintenance (2001), Accidents Related to Building Safety since 1990, Home page of the Task Force, Hong Kong SARG)

2.4.2 Economic Aspect: Retaining or Even Enhancing Property Value

It is pretty near that all buildings start to deteriorate as soon as they are completed (Baum, 1993). For that reason, one of the main purposes of maintenance is to offset the effect of physical deterioration and depreciation in value (Seeley, 1987). There has been wide recognition of the wider socio-economic repercussions resulting from lack of proper maintenance (Lee, 1995). The knock-on effect may end at rapid depreciation of an asset's value (Shabha, 2003). As a whole, these grounds which call for maintenance in economic aspect are passive in nature.

On a more aggressive maintenance approach, refurbishment is expected to enhance the market value of a property despite few empirical studies justifying the statement (Chau, *et al.* 2003; Young *et al.*, 2003). Indeed, theoretical models developed throughout the years often use refurbishment or rehabilitation as a factor against deterioration and determines the property value in the housing market. The positive impact brought about by refurbishment which in turn drove building owners to think of refurbishment or even rehabilitation in deciding an optimal maintenance policy (Sweeney, 1974; Dildine and Massey, 1974; Ohls, 1975; Arnott el al., 1983; Vorst, 1987). Maintenance also imposed positive effect on their neighbourhood value (Pavlovand and Blazenko, 2005).

It is not until recently attempts are made to justify the proposition through empirical studies. Before that studies were just based on simulation with positive effects of refurbishment on property value as the underlying assumptions (Wong and Norman, 1994; Dubin, 1998). Chau *et al.* (2003) and Hui *et al.* (2008) carried out empirical studies to exam the value enhancement of properties in Hong Kong from refurbishment and rehabilitation respectively. Using the transaction records of two large and popular estates in Hong Kong namely Pokfulam Garden and Chi Fu Fa Yuen, Chau *et al.* (2003) revealed that the refurbishment brought about approximately 9 percent increase in market value of the properties, whereas Hui *et al.* (2008) examined over 80 sample buildings across Hong Kong. The results showed that the rehabilitated buildings outweighed other buildings in the same district in the overall appreciation rate and the average increase in price. The benefit to cost ratio of rehabilitation per unit is 10.9 with the net benefit per square foot being HK$461.4 (or US$59.2).

2.4.3 Legal Aspect: Statutory and Legal Obligations

By reason of liability for defects as well as liability of occupiers, builders and building occupants are obliged to maintain buildings in due course. For liability for defects, it can be further classified into that between the developer and his contractor and that between the developer and the purchaser (HKLRC, 1995), whereas the works should be good and workmanlike using prescribed materials.

No matter new construction, repair or replacement work it is pretty near that there are always contracts between the employer and the contractor. Standard form of building contracts, for example, FIDIC Construction Contract which are used extensively in civil works worldwide, usually stipulates a clause requiring the contractor to make good of defects that appear within the Defects Liability Period (DLP). The Hong Kong Standard Form of Building Contract introduced in 2005[15] also stipulated similar clause of liability for defects in clause 15 where the DLP starts immediately after the issue of the Practical Completion Certificate and the period is normally 6 months to 1 year (Hills, 1995)[16]. Within this period, contractors are obliged to fix the defects. Nevertheless, the Certificate of Making Good Defects issued upon expiry of the DLP does not end the contractors' liability for the cost of remedying defects. Under the Limitation Ordinance[17], the liability period of any breach in complying with the contract specification is 6 and 12 years for ordinary and contracts under seal respectively.

On the other hand, occupiers are required to take responsible steps to maintain their properties. In the absence of due care, they are liable for any injury or damage to persons or goods caused by their property. The Occupiers Liability Ordinance in Hong Kong[18], for example, vested and prescribed the preceding occupier's liability. Apart from this passive enforcement, the Buildings Department (BD) may carry out routine inspection to check for dilapidation or defect in a building[19 and 20]. Unauthorized Building Works (UBWs) often result in dangerous building and they are fought against by BD too. An order in writing will be served by the Building Authority (BA) to require remedial works if a building has been rendered dangerous, or any dilapidations or defects are found. Failure to comply with the order is a criminal offence and fines will be charged. Almost

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[15] HK Standard Form was jointed introduced by the Hong Kong Institute of Architects (HKIA), the Hong Kong Institute of Construction Managers (HKICM) and the Hong Kong Institute of Surveyors (HKIS)

[16] In UK and Singapore, the DLP is 6 months and 1 year respectively

[17] HK Laws Cap. 347 Limitation Ordinance

[18] HK Laws Cap. 314

[19] HK Laws Cap. 123 Buildings Ordinance S.26, 'Where in the opinion of the Building Authority any building has been rendered dangerous or liable to become dangerous by … dilapidation, … the Building Authority may by order in writing served on the owner declare such building to be dangerous or liable to become dangerous

[20] HK Laws Cap. 123 Buildings Ordinance S.26A, 'Where, on inspection, the Building Authority finds any dilapidation or defect in a building he may by order in writing served on the owner of such building require such works as may be specified in the order to be carried out.'

equally worst, such order will be record in the Land Registry. It is an encumbrance on the property title and definitely imposes difficulties in transacting and financing the property, thus affecting the property value.

2.5 An Overview of Building Maintenance in Hong Kong

2.5.1 Economic Scale of Local Building Maintenance

Notwithstanding the fact that the property and construction sector contributes approximately 25 percent of Gross Domestic Product (GDP) (Ho, 1997), the investment in building management and maintenance has represented only a relatively small part of the economy in Hong Kong (Baldwin, 1993; Ho, 1994). In their work, Leung and Yiu (2004) compared the total gross value of maintenance work done (GVM) (Table 2.5) and the total service income of real estate maintenance management (REMM) against the GDP from 1981 to 2001. They revealed that in year 2001 GVM and REMM represented only about 1.8% and 1.6% of the GDP respectively (Figure 2.7). Besides, GVM accounted for less than 12% of the total gross value of construction work (GVC) done.

Base on their work, it is observed there is a rapid increase of GVM and REMM despite the low figure contributing to the overall GDP. GVM and REEM in real terms have been increased by threefold and 13 times accordingly in the past two decades (Figure 2.9). It is noted that the income from REMM and GVM have been increasing continuously although this growing trend of GVM was affected by the Asian Financial Crisis in 1997. In the future, similar trend is expected to remain for the problem of aged buildings in Hong Kong becomes more evident (Chan and Yiu, 2004).

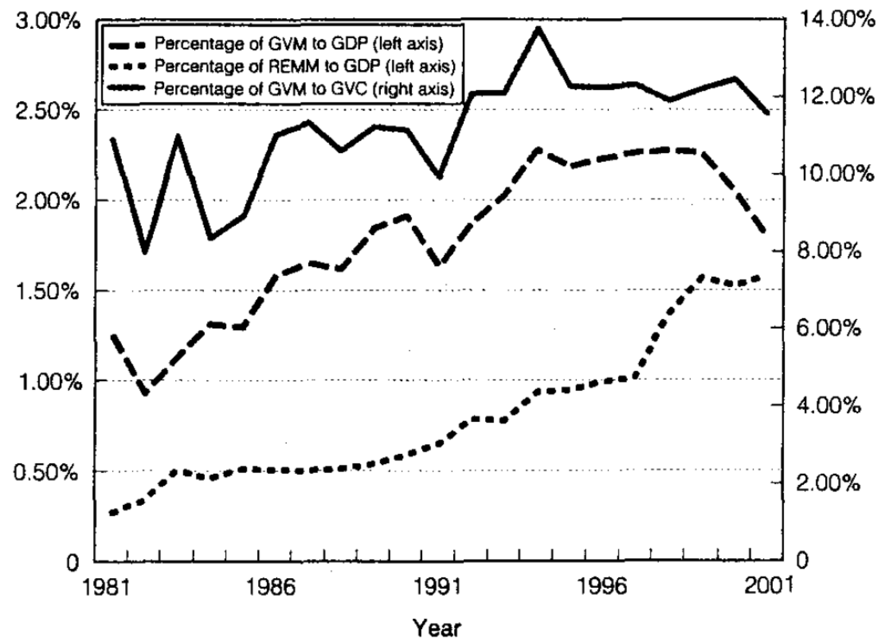

Figure 2.7 Economic Significance of Building Maintenance and Management (adapted from Leung and Yiu, 2004; source: Census and Statistics Department, HKSARG (various issues), Report on Annual Survey of Building, Construction and Real Estate Sectors, Hong Kong)

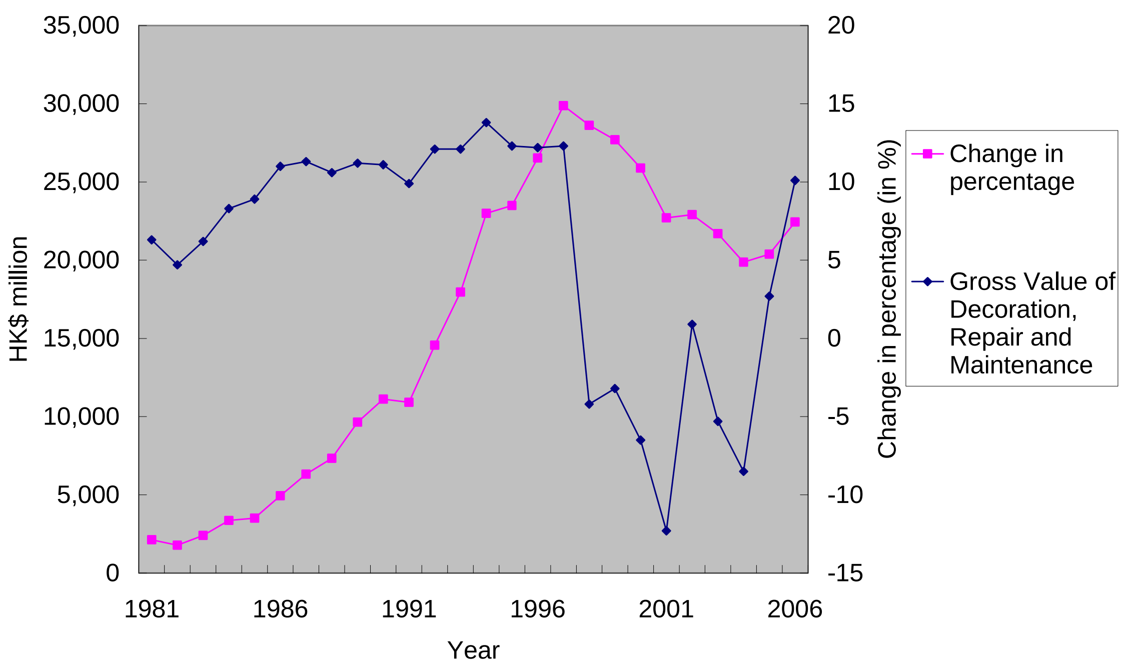

Figure 2.8 Figure showing the gross value of decoration, repair and maintenance in Hong Kong (Source: Annual Survey of Building, Construction and Real Estate Sectors 1981 to 2006, Census and Statistics Department, HKSARG)

Year	Gross Value of Decoration, Repair and Maintenance (HK$ Million)	Change in percentage (in %)
1981	2,127	6.3
1982	1,782	4.7
1983	2,409	6.2
1984	3,362	8.3
1985	3,510	8.9
1986	4,939	11.0
1987	6,324	11.3
1988	7,335	10.6
1989	9,650	11.2
1990	11,118	11.1
1991	10,913	9.9
1992	14,567	12.1
1993	17,964	12.1
1994	22,992	13.8
1995	23,500	12.3
1996	26,530	12.2
1997	29,874	12.3
1998	28,622	-4.2
1999	27,694	-3.2
2000	25,891	-6.5
2001	22,711	-12.3
2002	22,911	0.9
2003	21,693	-5.3
2004	19,874	-8.5
2005	20,388	2.7
2006	22,439	10.1

Table 2.5 Gross value of decoration, repair and maintenance in Hong Kong, numeric form of Figure 2.8 (Source: Annual Survey of Building, Construction and Real Estate Sectors 1981 to 2006, Census and Statistics Department, HKSARG)

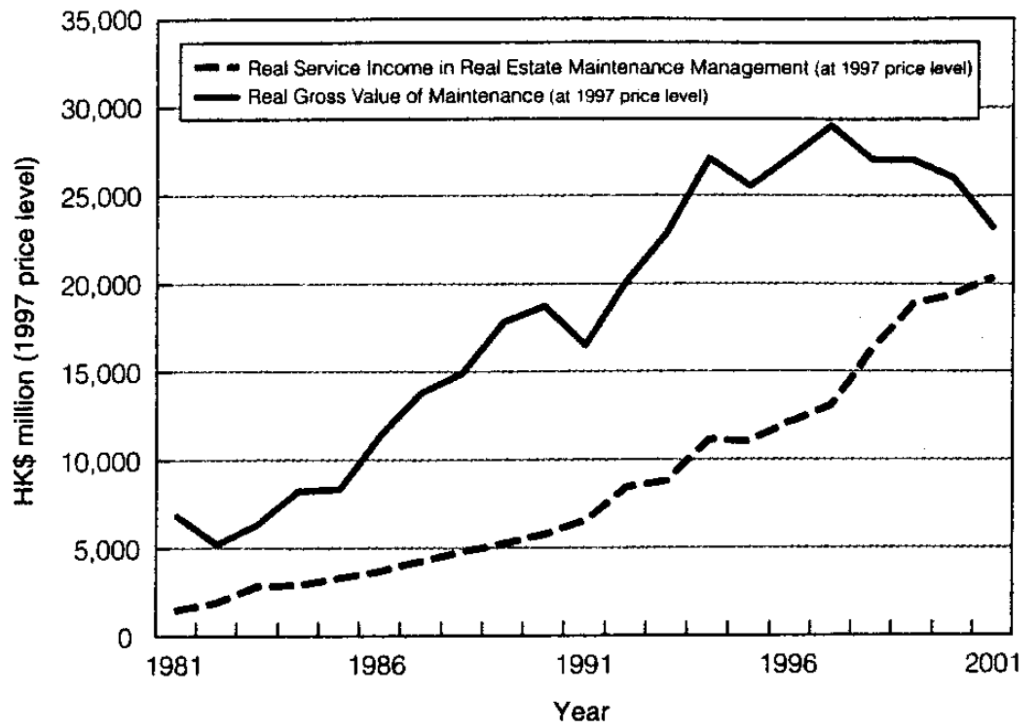

Figure 2.9 Real Gross Value of Building Maintenance and Real Service Income of Maintenance Management (adapted from Leung and Yiu, 2004; source: Census and Statistics Department, HKSARG (various issues), Report on Annual Survey of Building, Construction and Real Estate Sectors)

2.5.2 Common Building Problems and Building Defects in Hong Kong

From Table 2.4 it is obvious that every year there are at least a few building-related accidents with casualties[21] in Hong Kong, under which a significant part of these accidents are linked with Unauthorized Building Works (UBWs) (Table 2.6). It is not until today that the proliferation of UBWs has been identified as one of the major building problems in Hong Kong (Lai and Ho, 2000; Leung and Yiu, 2004; Yiu, *et al.*, 2004; Wong *et al.*, 2007). In their work, Lai and Ho (2000) classified these unauthorized structures into the following three broad types in accordance with their functions:

[21] Please refer to note 11, it summarized the number of accidents in Private Buildings only. The full list of building related accidents is available at web site of the Task Force of Building Safety and Preventive Maintenance, HPLB, HKSARG http://sc.info.gov.hk/gb/www.devb-plb.gov.hk/taskforce/eng/info/arbs.htm

Type 1: advertisement sign boards projecting from external wall or resting on roof tops and satellite discs for television and mobiles phones

Type 2: improvised measures to enhance the amenities of property, such as canopies above windows, flower racks

Type 3: structures to create space for human habitation

Apart from the Unauthorized Building Works (UBWs) reported, other commonly found building problems in Hong Kong include dangerous buildings, dangerous advertising signs and defective drains[22] (Table 2.7). Playing second fiddle to UBWs, dangerous buildings are not uncommon in Hong Kong (Figure 2.10). Literally, they can be interpreted as ‘buildings that are (structurally) unsafe which may cause harm or even injury’[23]. Since thousands of reports of dangerous buildings are received every year[24], by inference, at least this figure of safety hazards is now present in our built-environment. The result may merely show the most ideal situation; even worse, far more hidden, dangerous buildings are yet to be identified. Another thing to be highlighted is the compliance rate to the statutory order issued on these building problems. Chan (2004) compared both the number of statutory orders issued and the number of compliance with these orders from 1998 to 2002 and concluded that such rate is decreasing. In spite of the relatively short period of tracking, the message conveyed is rather alarming. First, the effectiveness of enforcing the Buildings Ordinance is questioned. There must be causes for building owners dare not to compliance with the statutory order. Second, the public is at risk since their safety is not safeguarded by law. These reasons, together with the recurring, building-related accidents, may probably explain why the Mandatory Building Inspection Scheme is tabled.

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[22] According to the statistics from the Buildings Department

[23] As defined in the Buildings Ordinance (HK Laws Cap. 123), ‘dangerous building’ means any building in such a condition as to cause risk of injury either to the occupiers or users of such building or to the occupiers or users of such building or to the occupiers or users of any neighbouring building or to the general public

[24] These reports are collected passively: from the media and members of the public and referrals from other Government departments, in which these buildings are qualified as dangerous buildings as defined in the buildings ordinance

Date	Accidents	No. of Deaths	No .of Injuries
17 Aug 1990	Collapse of a canopy with UBWs in Mong Kok	1	0
27 Oct 1990	Collapse of a canopy with UBWs in To Kwa Wan	6	9
15 Oct 1993	Collapse of a balcony with UBWs in Yau Ma Tei	0	4
01 Aug 1994	Collapse of a canopy with UBWs in Aberdeen	1	16
15 Nov 1995	Collapse of an illegal canopy in Kwun Tong	1	2
16 Apr 1997	Collapse of a canopy in Kwun Tong	1	0
19 Jul 1997	Collapse of a balcony in North Point	0	5
21 Oct 1997	Collapse of an illegal cantilevered metal cage in Mong Kok	0	1
06 Jan 1998	Fire in unauthorized alterations in an exit route in North Point	2	49
31 Jul 1998	Collapse of an illegal canopy in Kwun Tong	1	3
14 Sep 1998	Fire in tin huts illegally built in Wan Chai	2	13
03 Oct 1998	Fire on a rooftop with illegal structures in Mong Kok	0	0
11 Dec 1998	Fire on a rooftop with illegal structures in Sau Mau Ping	0	0
17 Jan 1999	Fire on a rooftop with illegal structures in North Point	0	0
09 Feb 1999	Fire on a podium with illegal structures in Kwai Chung	0	5
24 Feb 1999	Fire in a flat with an illegal alteration in Mong Kok	0	0
07 May 1999	Fire in an illegally built workshop in Kwun Tong	0	0
10 Aug 1999	Falling of masonry from an illegally built canopy in Mong Kok	1	0
11 Aug 1999	Collapse of an illegally built ceiling in North Point	0	0
10 Sep 1999	Collapse of an illegally built ceiling in Mong Kok	0	1
03 Oct 1999	Collapse of an illegally built podium in Tai Kok Tsui	0	2
22 Nov 1999	Fire in illegal structures behind a building in Yau Ma Tei	1	8
01 Dec 1999	Fire in an illegal structure on a rooftop in Sham Shui Po	1	2
02 Mar 2000	Fire in an illegal rooftop structures in Tsuen Wan	2	5
02 Dec 2000	Fire in an illegal rooftop structure in Hung Hom	0	0
02 Mar 2001	Fire in an illegal rooftop structure in San Po Kong	0	0
07 Mar 2001	Collapse of external walls of illegal rooftop structures during demolition in Ngau Tau Kok	0	0
17 Apr 2001	Collapse of an illegally built canopy in Kowloon City	0	1
08 Jun 2001	Collapse of the roof of an illegally built unit in Chai Wan	0	0
25 Mar 2002	Collapse of an illegal balcony in To Kwan Wan	0	7
11 Aug 2002	Collapse if an illegal balcony during demolition in Kwun Tong	1	2

Table 2.6 Sample of Accidents Related to UBWs from 1990-2002 (adapted from Leung and Yiu, 2004; source: Lai and Ho (2001); Task Force of Building Safety and Preventive Maintenance (2001))

Year	Dangerous Buildings	Dangerous Hillsides	Dangerous Advertising Signs	Unauthorized Building Work	Defective Drains	Total Nos. of Reports
1998	3,851	53	250	12,577	296	17,027
1999	4,730	130	614	16,999	365	22,811
2000	4,280	71	260	13,911	334	18,856
2001	6,671	41	178	12,764	552	20,206
2002	5,956	52	135	21,844	574	28,561
2003	8,665	48	181	24,870	2293	36,057
2004	10,407	146	303	21,123	2348	34,327
2005	13,999	208	331	25,683	2683	42,904
2006	6,758	183	564	24,861	4432	36,798
2007	4,566	128	322	24,633	4455	34,104

Table 2.7 Reports received about Dangerous Buildings, Hillsides, Advertising Signs, Unauthorized Building Work (UBW) and Defective Drains from 1998 to 2007 (source: Buildings Department 1998-2007)

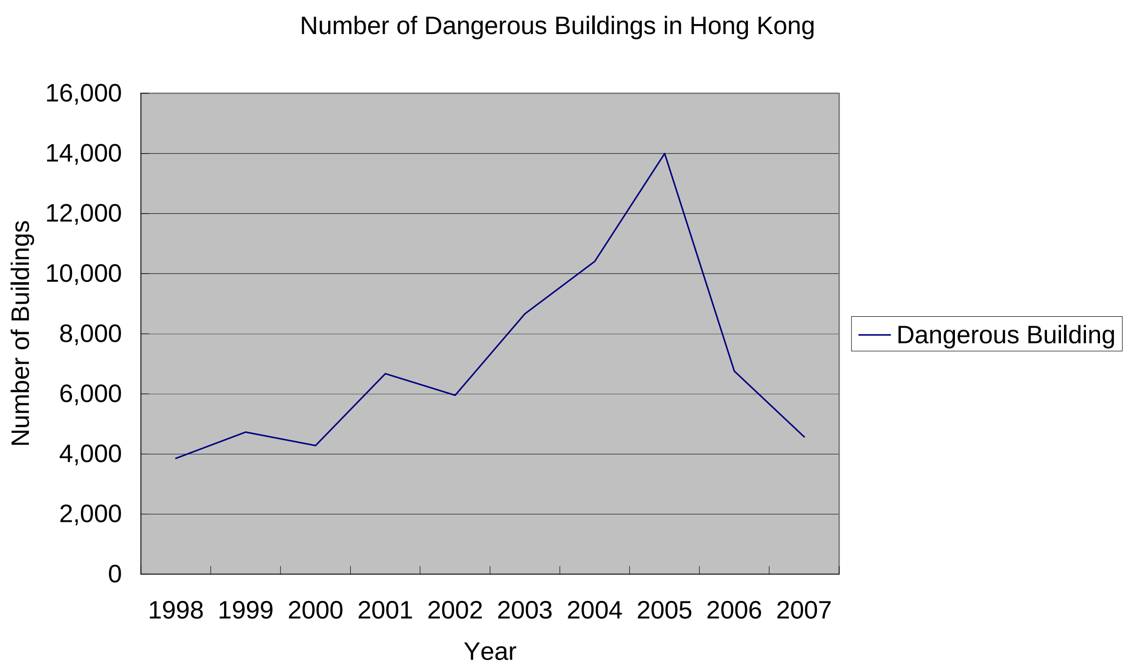


Figure 2.10 Figure showing the latest situation of dangerous buildings in Hong Kong (source: Buildings Department 1998-2002)

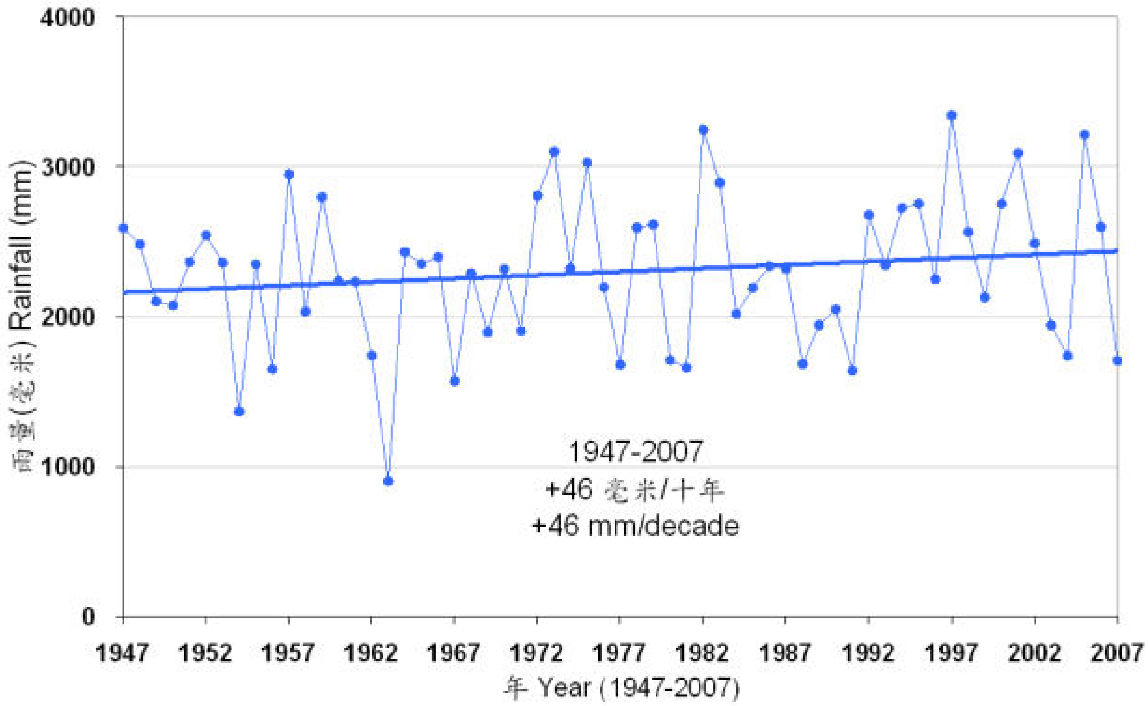


Figure 2.11 Annual rainfall in Hong Kong and its trend from 1947-2007 (adapted from Hong Kong Observatory, HKSARG)

Regarding other building problems in Hong Kong, there is one which always connected with the local climatic conditions, or in one word, water. Characterized by the subtropical climate, the annual rainfall in Hong Kong is high (Figure 2.11) and consequently there will be more chances for building enclosure to be come into contact with water. The leakage and seepage problems were highlighted by Chiang and Tang (2002) who pointed out a few building defects relating to water including water leaks through external walls (Figure 2.12), around windows (Figure 2.13) and from roof ceilings. More importantly, they attempted to grasp the magnitude of leakage problems in buildings by referring to a confidential, internal memo of a new downtown residential development developed by a major, local developer. In this case, report on water leakage amounted to 10% of over 70000 complaints filed by the homebuyers and it is worthwhile to point out the problem of building defects in new buildings. Alternatively, reference was made to the complaints received by the Hong Kong Consumer Council on substandard works found in newly completed housing units. 340 complaints are received only in the first 7 months of year

2000. Base on this figure, it is therefore interpreted that a complaint was lodged in every 40 newly completed domestic units.

As for building defects, it is considered that they arise due to two main reasons – nature and human errors (Pheng and Wee, 2001). It is quite obvious that building problems and building defects are two different concepts – building problems are usually human errors such that defects are the end result. In the following some common building defects under climatic conditions similar to Hong Kong found from literature are listed (Chew and De Silva, 2003; Chew *et al.* 2004) (Figure 2.14 and Figure 2.15):

- Leakage at ceilings
- Paint defects
- Leakage and corrosion at pipes (Figure 2.16)
- Concrete spalling and cracking (Figure 2.17 and Figure 2.18)
- Fungi and algae growth (Figure 2.19)
- Water ponding
- Staining/ discolouring of tiles
- Cracking/ debonding of tiles

Figure 2.12 Photo showing water leakage problems inside an old building

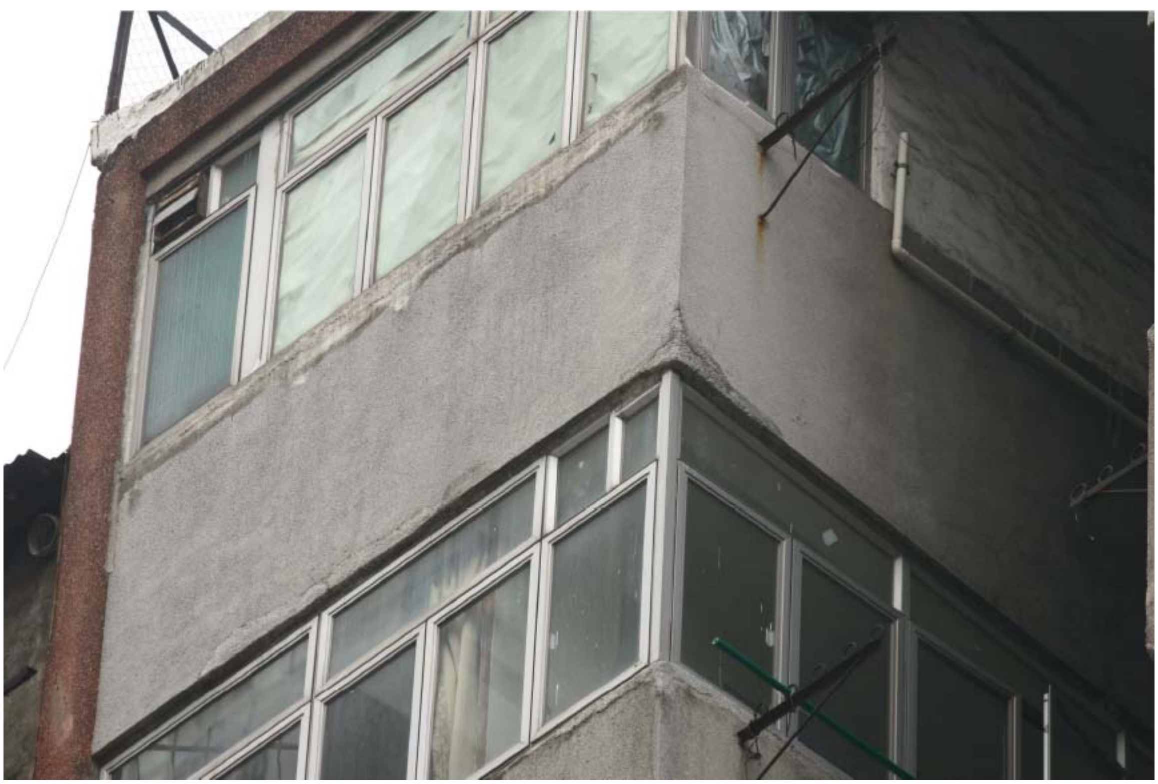


Figure 2.13 Photo showing water leakage problems at window in an old building

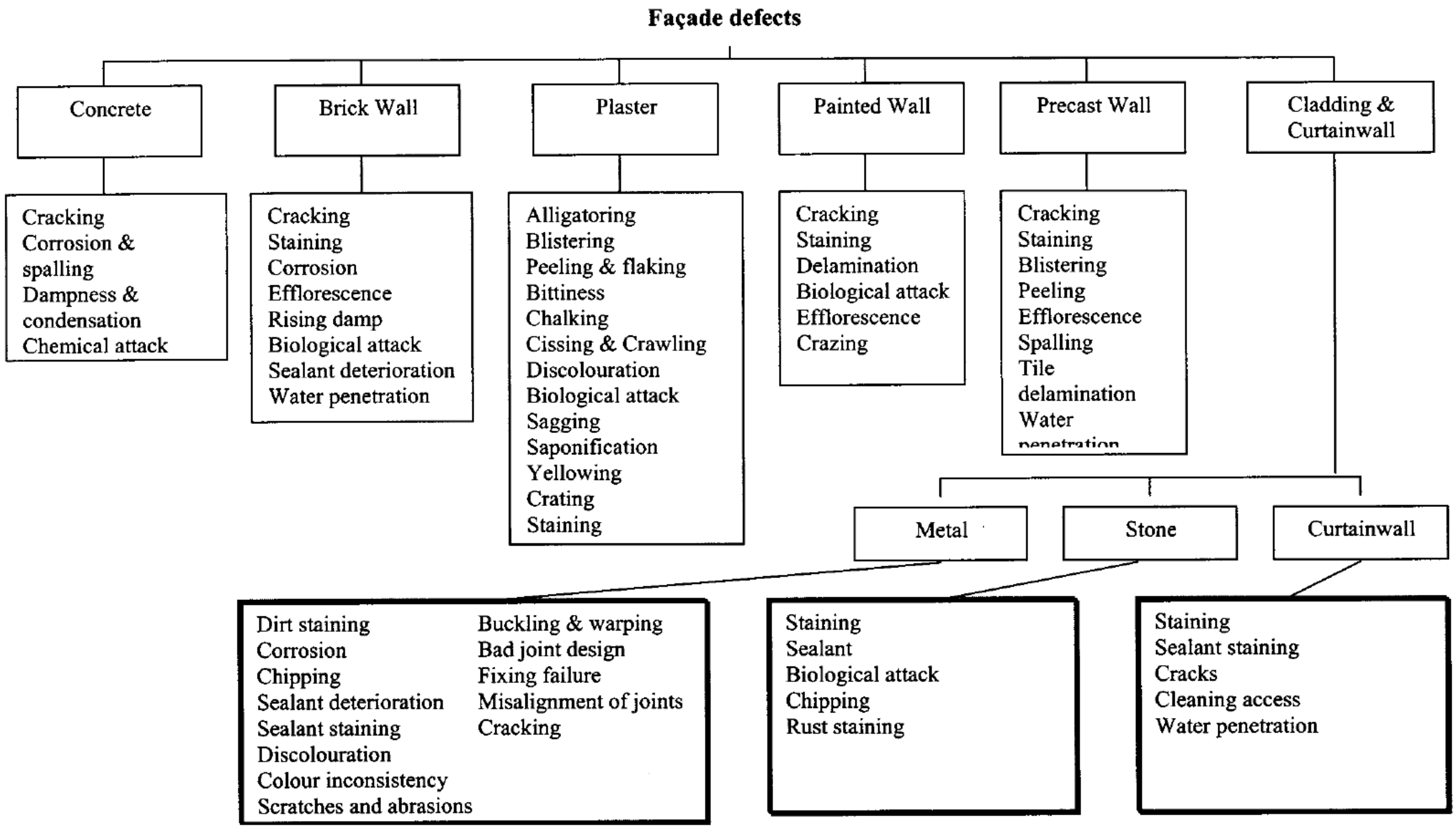


Figure 2.14 Building Defects found in façade that identified by Chew *et al.*, 2004 (source: Chew *et al.*, 2004)

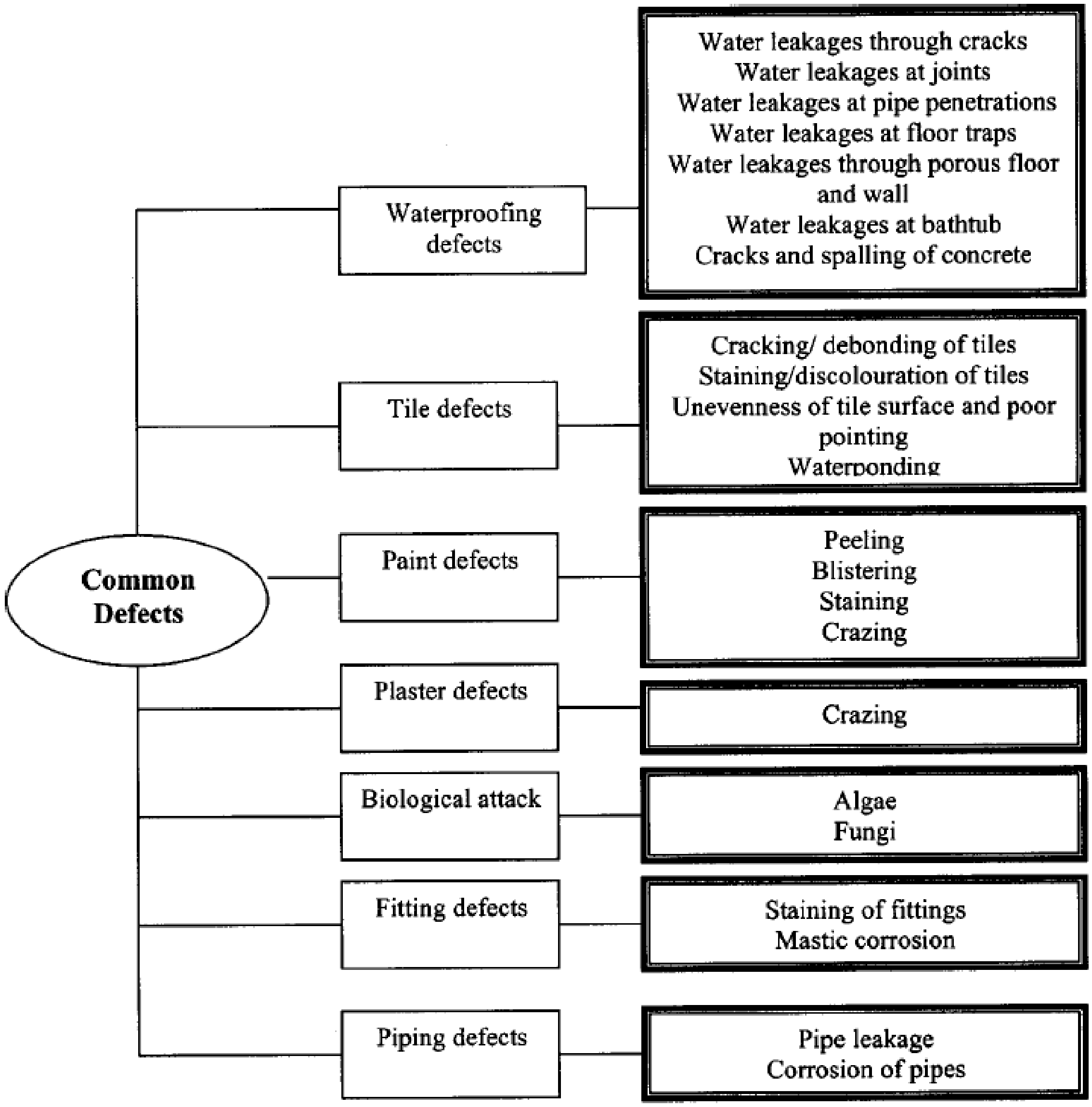


Figure 2.15 Wet Area defects identified by Chew *et al.*, 2004 (source: Chew *et al.*, 2004)


Figure 2.16 Leakage and corrosion at pipes


Figure 2.17 Concrete cracking

Figure 2.18 Concrete spalling

Figure 2.19 Fungi and algae growth around leaked pipes

In summary, accidents which cost lives are one time too many – building-related accidents should be prevented and free from any built-environment, especially in those high-rise and highly dense cities like Hong Kong. From the figures shown in Table 2.5 and Table 2.6, it is quite sure that there is still quite a long way to go before reaching the objective to create an accident free built-environment. Whilst for building defects, building performance in various aspects will be affected due to their presence. Disregard of their presence may eventually lead to another building-related accident which costs money, and above all, lives.

2.5.3 Legislations Regulating Building Maintenance in Hong Kong

Further to the liability for defects and liability of occupiers, the duties of owners to maintain buildings in Hong Kong are principally on the basis of the common law, a number of statutes (i.e. local legislations) and the Deed of Mutual Covenant (DMC). They altogether provide the legal framework which regulates building maintenance in Hong Kong.

On account of Hong Kong's colonial history, her judiciary is governed by common law system. Common law, or more precisely the law of tort in the context of building maintenance, provides that someone is liable for negligence if the duty of care owed by him/ her to other person has been breached. In this sense, every single building owner or occupier is obliged to repair and maintain their properties diligently (Buildings Department, 2002).

The legislation regulating building maintenance in Hong Kong primarily includes the Building Ordinance[25], the Building Management Ordinance[26] (BMO) and their subsidiary legislations[27]. Strictly speaking, not only building maintenance but also the majority of affairs relating to private buildings and their works is governed under the

[25] HK Laws Cap. 123
[26] HK Laws Cap. 344
[27] Such as HK Laws Cap. 123D Building (Escalators) Regulations, Cap. 123E Building (Lifts) Regulations and Cap 123I Building (Standards of Sanitary Fitments, Plumbing, Drainage Works and Latrines) Regulations

Building Ordinance. In short, this legislation intends to regulate and ensure the planning, design and construction of buildings, as well as associated and maintenance works, to attain basic safety and hygiene standard through measures such as requiring contractors and specialists to register and empower the Authority to issue orders to property owners for any violations of building laws found in their properties (Building Department, 2002; Lai and Ho, 2002).

On the other hand, in the absence of a framework within building individual owner can hardly handle the building matters effectively and efficiently. The underlying problem is that they do not have the necessary authority and no agreed procedures to settle the matters. Consider gigantic housing estates such as Mei Foo Sun Chuen and Taikoo Shing in Hong Kong with more than 60,000 and 40,000 inhabitants respectively, definitely, it would be hills of hurdles to be overcome by building owners must overcome in acquiring consent from their neighbours. Thus, the purposes of the BMO are to assist building owners to form a dedicated body, the Owners' Corporations (OC) and set up corresponding rules and regulations to facilitate daily management. Notwithstanding the enactment of the BMO, Lai and Chan (2004) revealed that older urban estates tend to have fewer owners to form the owners' corporations. In spite of presence of OC in most buildings, survey result revealed that quite a number of residents neither attended meetings organized by the OC nor went over the meeting minutes (New Century Forum, 2007).

2.5.4 Proposed Mandatory Building Inspection Scheme (MBIS)

Against the series of fatal concrete spalling accidents, it has been more than 10 years since the government first tabled the Mandatory Building Inspection Scheme in 1997 (Buildings Department, 1997; Tai Kung Pao, 1997), however, when the scheme was first introduced strong opposition from the general public and the political parties was attracted (Apple Daily, 1997; Ming Pao, 1997; Lee, 1999). The Authority could do nothing but launched a voluntary inspection scheme serving the intended purpose in an alternative, non-statutory way.

The MIBS was proposed to mitigate the problems resulting from "inattention of building conditions" and create a safer built environment. It requires private building owners to employ authorized personnel[28] to carry out building safety inspection at a regular interval ranges from 5 to 10 years (Buildings Department, 1997). Notwithstanding the changes in attitude towards the scheme throughout the years[29], financial concern is always the main reason that restrains the scheme from implementation, that is, the costs incurred in inspection and subsequently, the maintenance and repair fee to make good defects. As stated by a government spokesperson lately, it is estimated that the fee for inspection varies from HK $400 to HK$2,400 and repair costs can as high as HK$40,000 per unit (Sing Dao Daily, 2007).

Furthermore, there has not been consensus on the frequency of inspection and the age of building to be covered by the scheme. Details of inspection were not agreed too. Thus, two public consultations have been held on this issue in early 2004 and late 2005 respectively on the issue (HPLB, 2005). The findings are given in Table 2.8. Probably because of the more frequent occurrence of accidents connected with building, such as falling defective aluminum windows from height (Hong Kong Economic Times, 2008; Sing Pao Daily, 2008; Sing Tao Daily, 2008), the public have changed their mind to MIBS. Separate surveys conducted by Democratic Alliance for the Betterment and Progress of Hong Kong (DAB) and New Century Forum showed that the public as a whole are more willing to accept the scheme (DAB, 2005; New Century Forum, 2007) (Table 2.9). All this evidence points to that the legislation of MIBS seems imminent. The draft of MIBS will be discussed in the Legislative Council and it is expected the MBIS is going to be implemented by year 2009. As a result, to help MIBS so as to cut inspection and repair costs, building design and management should enable execution of maintenance tasks with ease.

[28] Authorized personnel may refer to Authorized Person (AP) or Registered Structural Engineer (RSE) to make building safety inspection

[29] See the following paragraph reporting the results of public consultation by the government and the surveys conducted by DAB and New Century Forum on the subject

Key Findings:
• About **88%** of respondents agreed that buildings at or above a certain age should be mandated to undertake building inspection
• About **52%** of them further agreed that building owners should bear the costs of such building inspection
• About **39%** of them suggested that buildings over **20** years old should be mandated for building inspection; and about **30%** of them suggested a stricter requirement to mandate inspection of buildings over **10** years old
• About **21%** of them suggested that inspection should be made every **10** years, and about **43%** of them asked for a higher requirement of every **5** years
• About **83%** of respondents agreed to mandate building inspection for buildings without Owners' Corporations or not serviced by property management companies

Table 2.8 Key findings in Public Consultation on Building Management and Maintenance initiated by HPLB (source: HPLB, 2005)

Proposed Movement	Percentage of Support		
	Government Consultation	DAB (Sample = 682)	New Century Forum (Sample = 907)
Buildings should be inspected mandatorily	88%	73.8 (for building aged 30 years or above and the owners take follow-ups to repair)	78.6 (for building aged 30 years or above to be inspected for every 10 years)
Windows should be inspected mandatorily	/	68.6	61.9 (for building aged 10 years or above to be inspected every 5 years)

Table 2.9 Tabulated summaries and comparison of findings of the surveys by government, DAB and New Century Forum regarding MIBS (source: DAB, 2005; HPLB, 2005; New Century Forum, 2007)

2.6 Building Maintainability

2.6.1 What is Building Maintainability?

Simply speaking, maintainability may refer to ease of maintenance. At any rate, this definition is oversimplified. Definition of maintainability can be traced back to Blanchard and Lowery (1969) who defined maintainability as 'a characteristic of equipment design and installation which is expressed in terms of ease and economy of maintenance, availability of the equipment, safety, and accuracy in the performance of maintenance actions'. Fledman (1975) further developed and incorporated this concept into building as 'the condition for an item or a surface that permits its repair, adjustment, or cleaning with reasonable effort and cost'[30]. Since then, research on maintainability of building was very limited. Right before the millennium, another wave of research on maintainability of building was triggered in Singapore who has identified improving maintainability as one of the key initiatives to be aimed at in improving the Singaporean Construction Industry (CTC, 1999). Consequently, another definition of maintainability of buildings was proposed as 'achieving the optimum performance throughout the building life span within a minimum life cycle cost' (Chew and De Silva, 2003)[31]. Apart from this, Dunston and William (1999) considered maintainability together with constructability. From constructability point of view, 'optimal maintainability' is considered as 'the design characteristic which incorporates function, accessibility, reliability, and ease of servicing and repair into all active and passive system components, that maximizes costs, and maximizes benefits of the expected life cycle value of a facility'. In structural engineering, maintainability is defined as the extent to which it is feasible to restore product performance to the intended original minimum level within a given period of time (Bijen, 2003).

[30] In his book, Fledman (1975) further explained reasonable effort and cost, 'Reasonable effort and cost also means, by inference, that the maintenance must not require unusual worker skills or expensive equipment that is rarely used (although specialized equipment regularly used can be very economical), that it must not involve a procedure that will not permit the reuse of the item in a short time, and that it must not change the item's original appearance or require overly frequent attention.'

[31] In meantime, various research output had been generated by the National University of Singapore including the Maintainability Grading Systems, Online Defects Library, Material Manual and key aspects to improve maintainability of buildings in Singapore (e.g. promoting the use of D&B Procurement System)

When these definitions are considered collectively, it can be interpreted that maintainability stresses on ease and effectiveness of maintenance, which is, optimizing the maintenance process through planning, designing and managing facilities such that with a certain level of input the best outcome can be given. In this regard, less input is required to maintain a building with high maintainability whilst on the other hand the same or even better outcome is resulted. Hence, maintainability of building at a given time should be described as the extent building facilities allows for maintenance, which is keeping, restoring, or improving those facilities, to be expressed in terms of the resources required (e.g. economy of maintenance, manpower or machineries required, working hours needed, etc) and the performance of maintenance (e.g. interruption time, quality of maintenance, safety, etc).

On a separate issue, the concept maintainability of buildings and design for manageability should not be mixed up. Design for manageability, which is in fact a different concept, is proposed in the 1990s to eliminate unnecessary complexity and provide flexibility to users. Its goal is to increase efficiency and improve performance through designing building with more consideration from managerial perspectives (Leaman and Bordass, 1993; Bordass and Leaman, 1997). Comparing these two concepts it is believed that building maintenance is just one of the aspects in building (or property) management.

2.6.2 Why Building Maintainability - Soaring Cost in Maintenance and Deficiencies in Designs

The principle reason why building maintainability is put forward is to alleviate the problems associated with the soaring maintenance costs. The importance and economic scale of maintenance in Hong Kong have been reviewed in Section 2.5.1. Despite the relatively low proportion contributing to the overall local GDP, the absolute amount is still a huge figure. In the UK, it is estimated that expenditure in building maintenance accounts for some ￡20 billion in 1995 and definitely there will be a visible effect for any reduction in resources for building maintenance (Technology Foresight Construction Sector Panel, 1995; Horner *et al.*, 1997).

From literatures, the problems of soaring cost in maintenance have been widely realized by researchers and various reasons are given to explain this phenomenon (Griffin, 1993; Assaf *et al.*, 1995; Cane, 1998; Shen *et al.*, 1998; Dunston and Williamson, 1999). Assaf *et al.* (1995) blamed higher maintenance costs on the errors and defects made during deign and construction stages of large and complex projects, whereas similar views are expressed by Al-Hammad *et al.* (1997) and Dunston and Williamson (1999) for deficiencies in design resulting in more frequent occurrences of failing. The lofty maintenance costs are believed to be caused by substandard workmanship and malpractice in maintenance too (Assaf *et al.*, 1995; Ardit and Nawakorawit, 1999a, b), whilst Cane *et al.*, (1998) compared the maintenance and service costs of commercial building ground-source heat pump systems and revealed that the variances in costs depend on the system chosen. For these reasons, it is long believed that decisions made before construction (e.g. adequacy of design, building materials specified) are crucial for maintenance (Lee, 1987).

A comprehensive account in the significance of maintenance costs is given by Griffin (1993) who pointed out that a large proportion of total cost will occur during the in-service life, typically from 50% to as much as 80%. In other words, the costs of design, development, construction and manufacturing activities may be as little as 25%. Life cycle costing techniques therefore depict long-range financial picture of facilities[32and 33],

[32] Life Cycle Cost of an asset is defined as the Present Value (PV) of the total cost of that asset over its operating life, including 4 principle elements namely the initial capital cost, occupation costs, operating costs, and the cost incurred or benefit derived from the disposal of the asset at the end of its life (Ashworth, 1989)

[33] Equation of Life Cycle Cost is given as:

$$LCC = Ic + (Mc + Ec + Cc + Oc) + Vc - Rv$$

Where	Ic	=	Initial Cost
	Mc	=	Maintenance Costs
	Ec	=	Energy Costs
	Cc	=	Cleaning Costs
	Oc	=	Overhead and Management Costs
	Vc	=	Utilization Costs
	Rv	=	Resale Value

however, largely depends on the accuracy of estimation and costs-in-use and benefits from disposal are difficult to predict (Arditi and Messiha, 1996; Asiedu and Gu, 1998), and Asiedu and Gu (1998)[34] contended the accuracy of cost estimates is very essential for the survival of an organization. Unfortunately, the required amount of costs always mismatches with the available budget, in particular, the maintenance costs. For instance, Chan (1993) pointed out that the total maintenance budget available for maintaining government facilities in Hong Kong was once still less than 2% of the replacement value of the total asset for refurbishing the dilapidated buildings, whilst a minimum of 3.5% of the replacement cost was required to serve this purpose. Similar problems were encountered in the UK in the case of structural works in primary and secondary schools (DES, 1985). The soaring maintenance costs can be disastrous because no funding is available for many maintenance tasks which need imminent actions. All these evidences prompt a solution which can mitigate these problems and definitely design for maintainability is a way.

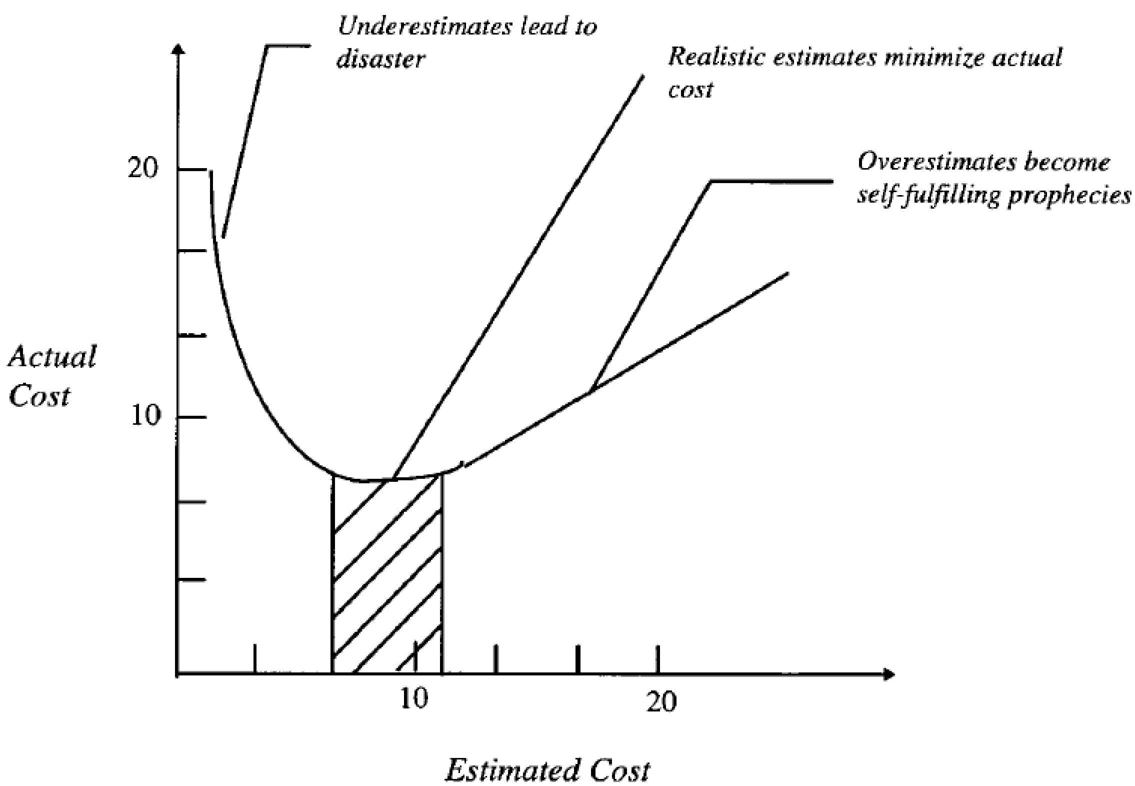


Figure 2.20 The Freiman Curve (source: Daschbach and Apgar, 1998)

[34] Asiedu and Gu stated, (1) The greater the underestimate, the great the actual expenditure; (2) the greater the overestimate, the greater the actual expenditure (Figure 2.20)

2.7 Attributes, Features and Practices Attributable to Maintainability of Buildings

2.7.1 Adequate Provision of Access

For the sake of ease of maintenance, providing adequate access is necessary for maintenance tasks to be carried out safely and economically. To achieve a high level of accessibility for maintenance, there should be sufficient working space for personnel, machineries and equipment in addition to enabling them to and from the point of maintenance easily without exposing to safety hazards. An example proposed by Blanc (1994) is that there should be no placing of ladders or access towers in areas where access is required by vehicles unless it is unavoidable. Therefore, planning the location of services and providing sufficient space in designs are equally important (Harrison, 1995; Wordsworth, 2001). Access requirement in both routine and periodic maintenance should be taken into account as well. To provide adequate access, the idea of flexibility should be incorporated during design. Through avoid designing permanent fixture, access can be granted for maintenance purposes. On the other hand, it is believed that failure to provide adequate access may restrain buildings from proper maintenance. Ho (1988) highlighted this problem using building services systems as an example. With adequate access to pipes and cables, opportunities for proper and timely maintenance can be provided.

Apart from gaining adequate, physical access to the point of maintenance which is discussed above, safety of access and gaining access to private, exclusive areas which are physically accessible for the purpose of maintenance is of vital importance too. Maintaining good relationship between the management company and building occupiers can be a way to alleviate the problem of denying access.

2.7.2 Maintenance Facilities, Plants and Equipment

Maintenance facilities play a significant role in maintenance by assisting maintenance personnel to overcome various limitations such as limitations in design and increase maintenance efficiency. Maintenance facilities may simply be interpreted as one of the inputs in maintenance besides human and financial resources. Thus, they include the services necessary for the execution of maintenance tasks such as water supplies for cleaning purpose, plants and equipment such as elevated working platforms and gondola to provide access at height, and space provide for management personnel to work and storing the aforesaid plants and equipments.

Shortcomings in design from maintenance perspective are not uncommon. In any case suitable facilities should be provided to facilitate maintenance tasks so as to meet the designated maintenance objectives. Consequently, low level of maintainability should refer to the situation that fails to come to a compromise between design and ease of maintenance. This suggests that neither of them should be taken sides but to find out an optimal solution that facilitate maintenance. Hence, design deficiency should not be blamed solely for low maintainability. To reach this win-win solution, involving parties in the project team notably the designers should take future maintenance needs into their account when they design and provide all necessary facilities. Moreover, as stated above, adequate access is crucial to facilitate maintenance. In any case considerations in the accessibility (e.g. location of storage, adequate headroom) of maintenance facilities to be provided should be given.

2.7.3 Awareness and Knowledge of Personnel in Maintainability

Very often, problems in maintenance are caused by neglecting the requirement of maintenance and designers are always the one to be blamed. In his text, Lee and Yuen (1993) mentioned this problem for designers are giving too much emphasis to aesthetics at the expense of maintainability. To alleviate this problem, it is generally perceived that the involvement of maintenance manager in new works is essential (White, 1979), and their participation should specifically be made during the design stage (Fledman, 1975; Armstrong, 1984; Watt, 1999), whereas Fledman (1975) took a further step by stating that future maintenance manager should be responsible for supervising the works during construction to facilitate future maintenance tasks.

Sole participation of maintenance managers during design stage is not sufficient for solving problems in future maintenance and enhancing maintainability. Other parties should attach equal importance to the opinions brought up by maintenance managers. Moreover, parties involving in building development and management should possess knowledge in technical and practical issues related to maintenance and maintainability (DoE, 1972; Bathurst, 1988; Al-Hammad *et al.*, 1997; Lo *et al.*, 2000; De Silva *et al.*, 2004). According to Watt (1999) who referred this issue to an unpublished work by the Polytechnic of Central London, three main roles and six sub-roles involving in building industry are identified for which adequate education and/or training was need and the findings are summarized below:

- Maintenance specialist
    - Building fabric
    - Building Services
- General Construction Practitioner
    - Economics
    - Design
    - Inspection
    - Construction
- Clients

It is, however, thought that achieving highly maintainability buildings right from the beginning it is of crucial importance for designers and architects as the key persons in the development process to possess knowledge in maintenance and maintainability. Clients nowadays should be trained too so that they can identify and deliver clear design briefs addressing their requirements including the maintenance performance they expected. In the meantime, staff's skill level and proficiency is required too for maintenance tasks to be carried efficiently, effectively and safely (Fledman, 1975; Pheng and Wee, 2001).

2.7.4 Design Decision

2.7.4.1 Choice of Materials and Building Systems

Proper choice of materials and buildings is undoubtedly essential for a building to achieve a high level of maintainability and an important aspect for future maintenance (Chew, 1992, 1998; Ho, 1998; Chew *et al.*, 1999; Chew and Zhou, 2002; De Silva *et al.*, 2004). In the following, this issue is going to be discussed in a few aspects namely nature of components, availability, frequency of maintenance.

Nature of Components

In general, the choice of building materials and various systems in building (e.g. building services systems and construction systems) are primarily to meet the users and functional requirement imposed. Considering maintenance right from the beginning of choosing material and systems are rare. In spite of this truth, it is advised that an optimal choice should be made between the aforesaid requirements and maintenance and neither side should be overlooked. Colour and texture of materials, for example, determine the frequency of maintenance significantly because less cleaning is required for materials with colours in which dirt trapped on it will not be spotted easily. Besides, whether the components are easy to maintenance largely depend on their way of fixing and installation. It is quite obvious that easy disassembly and assembly of components is an advantage in maintainability. For a component which enables diagnosis to be carried out in an expensive and time-saving manner, definitely, many efforts in maintenance can be saved.

Availability

It is not uncommon that the supply of building materials and components is superseded after a certain period of time. In planning and designing this issue must be addressed to ensure that there will be suitable parts as replacement throughout the life cycle of building materials and components. Ordering and keeping certain amount of extra parts as reserve right from construction stage can be a solution to this problem (e.g. 2% - 5% of wall tiles) or the costs incurred in manufacturing replacement will be extraordinarily high and long time is required for production. Alternatively, enabling the application of alternatives and designing for interchangeability can be other solutions.

Frequency of Maintenance

The frequency of maintenance largely depends on the material and systems chosen. Under most circumstance, the more durability an item, the less needs to provide maintenance. So, it is desirable to choose materials which require minimum maintenance. On the contrary, durable materials and systems are always more expensive. Furthermore, a hundred percent reliability can hardly be achieved in reality as stated (Blanchard, 1969). Needs for maintenance are always present. In this regard, materials which require minimum maintenance should be specified (e.g. materials which can be cleaned easily and do not trap dirt and duct easily) and those which need complete replacement should be avoided (e.g. carpet roll versus carpet tile)

2.7.4.2 Design Layout

In enhancing the buildability of buildings, uncomplicated and modular design layout can increase the site productivity significantly. The productivity on site can be further increased by allowing prefabrication of components offsite (Lam *et al.*, 2006). Buildability and maintainability of buildings are in principle two very similar concepts – buildability stress on ease of construction whilst maintainability stress on ease of maintenance. Indeed, use of standard details with lots repetition requires relatively low skill level and less variety of parts. Thus, less maintenance problem should be arose form simple and standardized design. The productivity of maintenance should at the same time be increased.

In addition, allowing prefabrication of maintenance components offsite together with easily disassembly and assembly of components may further increase the productivity of maintenance.

2.7.5 Proper Management

In addition to designing buildings which facilitate future maintenance, proper management of maintenance activities is of equal importance. To narrow down the scope of discussion, property management here stresses daily management other than maintenance management. For maintenance tasks to be carried out successfully with ease, this can hardly be done in the absence of all necessary resources such as documentations. As-built drawings, for example, which show the actual fitting of building components, should be kept and maintained well for maintenance personnel to make reference to in any maintenance. Therefore, all the necessary documentation, drawings, manuals and maintenance handbooks should be kept by the property managers or building owners. Having completed maintenance, records should be in logbooks for future reference. More importantly, these materials should be well managed, detailed and unambiguous, that is, able to providing useful information readily and conveniently in time of need.

Consequently, opposite to proper management of documentations for the sake of ease of maintenance, unauthorized or unacknowledged alteration to building will obstruct maintenance tasks to be executed smoothly.

2.7.6 Safety

Last but not least, safety obviously is one of the attributes affecting the maintainability of building. Before progressing, the significance of providing adequate access and those maintenance facilities which are necessary for the execution of maintenance on maintainability has been discussed in the previous sections. Nonetheless, access and facilities provided should be safe as well. Not only the aforementioned elements but safety considerations are also important for maintaining buildings with ease. To safeguard personnel against injuries, size and weights of materials and components should be safe for them to handle, or alternative plants should be available to provide assistance to them safely. The working environment should be hazard-free too (e.g. no harmful gaseous contents) and precautionary measures should be taken where necessary. Whilst in the course of design, designers are obligated to design for safe maintenance. Unnecessary design at height or below ground should be avoided. They should design for safe maintenance in areas with potential hazards.

Apart from physical elements, the awareness and knowledge of personnel in safety is decisive in creating an accident-free working environment for carrying out maintenance tasks and at the same time enhance building maintainability. This can be done by providing trainings and continual staff developments.

2.8 Summary

This Chapter has reviewed issues and studies in building maintenance and building maintainability. In the first instance, the idea of building maintenance is discussed. Building maintenance as a whole should be denoted as any measures taken to keep, restore or improve building facilities without extensive alternation or improvement. Building maintenance management and types of maintenance are subsequently discussed. Three types of maintenance including corrective maintenance, preventive maintenance and condition-based maintenance are introduced. Having established the theoretical framework in building maintenance, the needs to provide maintenance are investigated in physical, economic and legal aspects. Maintenance is necessary for guarding physical structures of building against deterioration and meantime well maintained structures are important to retain or even enhance the economic value of buildings. Building owners are forced to maintain buildings in sound conditions so as to fulfill the legal requirements. Following this is an in-depth review on a few selected maintenance issues in Hong Kong, which include the economic sale of maintenance activities, common problems and defects found in buildings in Hong Kong, laws that regulating building maintenance and the proposed MBIS.

For the second part which focuses on building maintainability, this concept is explored first to establish the theoretical framework. Then the reason why maintainability of building was brought up has been investigated, which is due to the soaring cost in maintenance. Maintainability of building is regarded as the way to save maintenance costs by promoting the idea of ease of maintenance. Subsequently, those factors that attributable to maintainability of buildings are reviewed. Providing adequate access is often ranked top in this subject, however, awareness and knowledge of personnel and availability of necessary maintenance facilities such as plants and equipment are important as well. Past works on building maintainability always consider design is the most critical factor affecting maintainability, in contrast, it is thought that proper management of the building after completion plays similar role in enhancing maintainability. Last but not least, safety considerations should never be overlooked and definitely it is essential in promoting ease of maintenance.

CHAPTER 3 RESEARCH METHODOLOGY

3.1 Introduction

On account of the limited time and resources available, the research methodology adopted for developing the Maintainability Assessment Model comprises structured interviews with property managers and maintenance managers to solicit their views on the subject of building maintainability. The principal aims of these interviews are to establish the Maintainability indices of individual items in the assessment model and decide the weightings which represent the relative importance amongst components in the model in terms of maintainability from the quantitative data obtained. In the mean time, the qualitative data collected are used to refine the assessment framework and probe into issue of building maintenance and maintainability in Hong Kong. In summary, the work-flow of this research is shown diagrammatically in Figure 3.1.

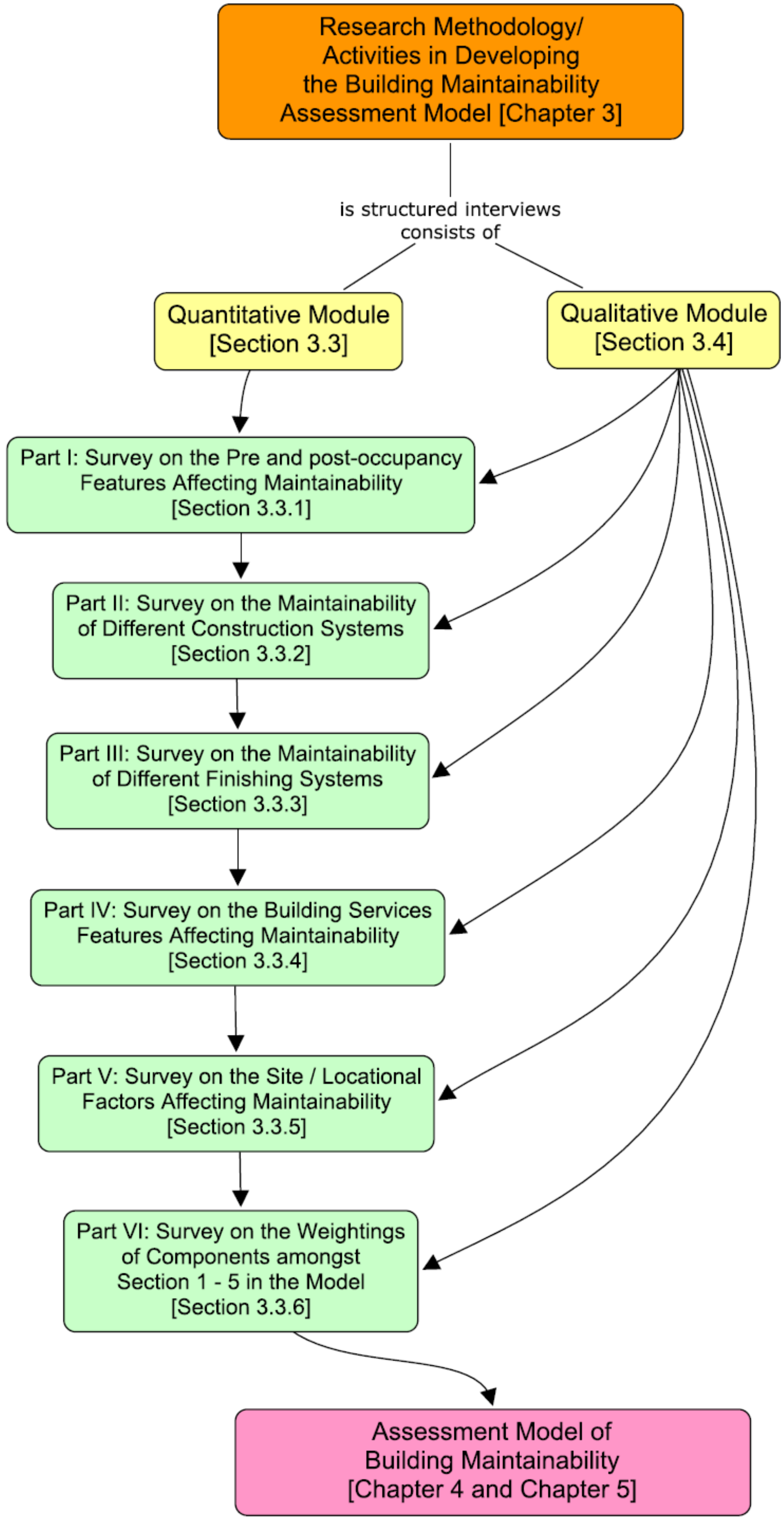


Fig 3.1 Illustration showing the work-flow of the structured interviews

3.2 Structured Interviews

Structured interviews are carried out with experience property managers and maintenance managers who are working for clients from both public and private sectors. The detailed methodology will be explained in depth in the following.

3.2.1 Structure of the Interview

The interview comprises 7 parts in which 6 of them are intended to obtain quantitative data (i.e. the quantitative module) for establishing the Maintainability indices of individual items and determine the weightings among the 5 components in the assessment model. The research design is modified from Lam *et al.* (2006). The 5 components include pre and post-occupancy maintainable practices, construction systems, finishing systems, building services systems and locational/ site factors. Throughout the interview, open-ended questions are raised by the interviewer on the subject of building maintainability. This is the qualitative module with an aim to collect interviewees' opinion to understand the current state of building maintainability in Hong Kong and refine the assessment mechanism. All the survey questions are sent to the interviewees at least one day in advance for them to familiar with and prepare for the questions.

3.2.2 Sample of Interviewees

Considering the entire life cycle of a building, the overall building maintainability is undoubtedly the aftereffect of the decisions taken by various parties, such as architects and property managers. Ideally, academic works should go for perfection and the best option is to interview all these aforesaid involving parties and professionals, nevertheless, by reason of time constraint, the preliminary targeted group of interviewees in this research are confined to those who are experienced in managing local properties, that is, property managers and maintenance managers who are practicing in Hong Kong. Moreover, the nature and objectives (such as maintenance objectives) are different in public and private sectors, to portray a holistic picture on the subject representative professionals from both public and private sectors are invited to the interview randomly. Senior and experienced personnel who hold key position in the field are regarded as ideal interviewees, for those with qualifications in relevant professional institutions or even council officers in these institutions are more preferable.

3.2.3 Language

Since the targeted interviewees are all experienced personnel who hold key positions in large-sized corporations and professional institutions, they are considered as very good users of English. To ensure the coherence, the questions in the questionnaire are all written in English without translating into Chinese; yet, the interviews are conducted in Cantonese to facilitate exchange of ideas and discussion on the subject.

3.3 Quantitative Module

3.3.1 Survey on Pre and Post-occupancy Practices and Features Affecting Building Maintainability

3.3.1.1 Objective

Serving as the first part to obtain quantitative data for developing the assessment model, the objective is to identify the factors that affect building maintainability and rank their relative importance towards the subject on the basis of closed questions. Furthermore, it is expected a list of key factors can be generalized which serves as guideline to improve maintainability. In this part, effects of pre and post-occupancy practices on maintainability are focused.

3.3.1.2 Methodology

This survey is divided into two parts concerning the effect of pre-occupancy and post-occupancy practices on building maintainability. Having undergone a rigorous literature review on ‘general maintainability’ and ‘building maintainability’ from planning stage to post-occupancy stage, 51 factors are identified which can be further grouped under 19 headings, with 15 and 4 in pre and post-occupancy stage respectively (Figure 3.2).

Pre-occupancy practices refer to considerations in planning, designing and constructing a building, for instance, criteria in selecting design option, materials and construction methods. For post-occupancy practices, they are mainly managerial elements that affect the implementation of maintenance tasks. A sample of the questionnaire is attached in Appendix A.

To complete this part, interviewees are requested to indicate their choice using the 5-point Likert Scale, in which ‘5’ implies a particular item which has a very high importance or impact on maintainability and conversely, ‘1’ indicates an item that has a very low importance or impact on maintainability. Under the circumstances where an item is considered as irrelevant or inapplicable to maintainability, interviewees are required to cross the scale off as shown in the example on the questionnaire. Since one of the objectives of this part is to identify the factors affecting building maintainability in pre and post-occupancy stage, space is provided for the interviewees to put in their comments and propose any other missing factors. Throughout the whole process, the interviewer will explain the questions actively and in any event interviewees are encouraged to raise any questions in the survey. All questions are handled at once to ensure fairness.

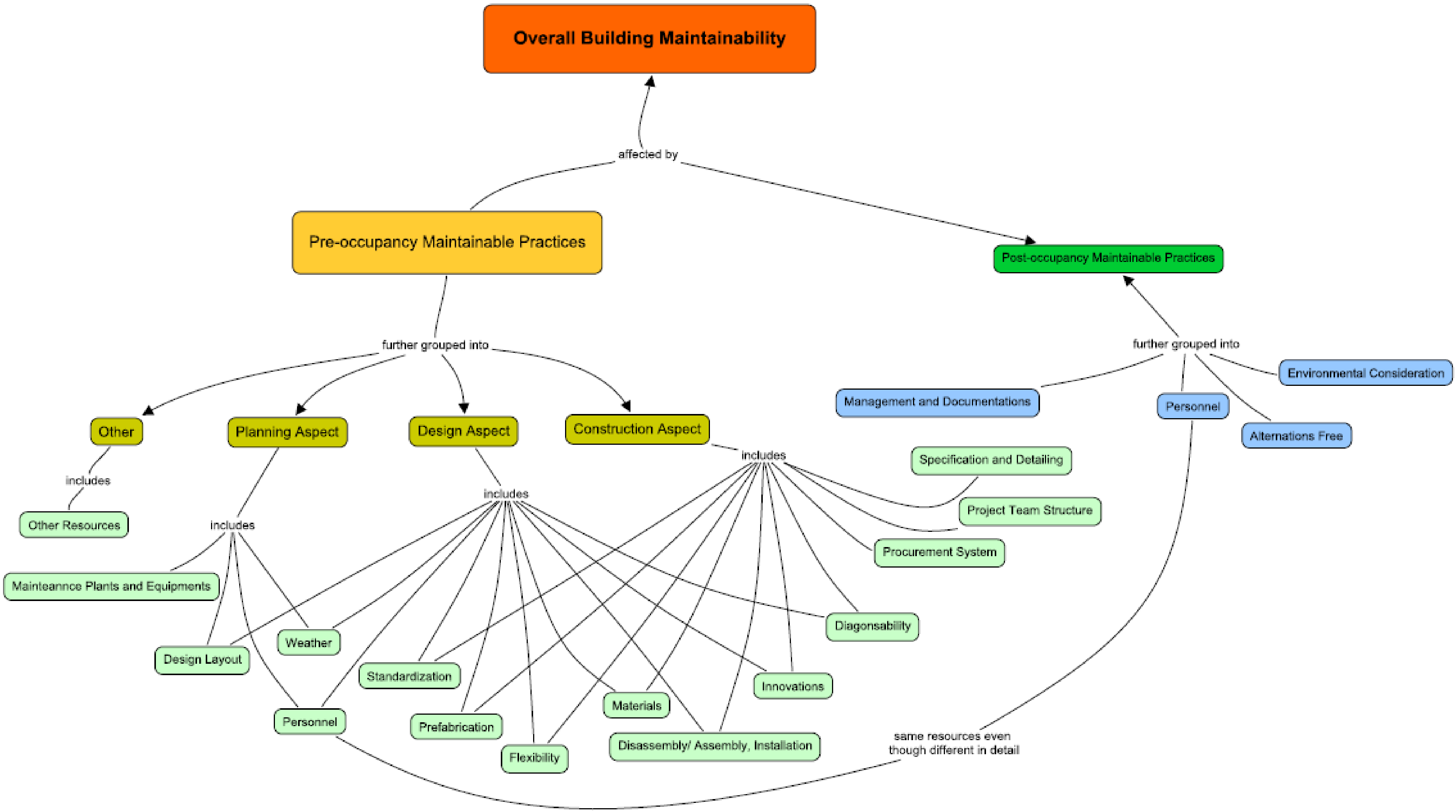


Figure 3.2 Maintainable Features which are grouped under the above 19 headings

3.3.1.3 Data Analysis

For the purpose of identifying key factors affecting maintainability and work out the relative importance of items quantitatively, three approaches are adopted. First of all, factor analysis is employed to consolidate the practices or features into key factors through the 'orderly simplification' process (Burt, 1940). Base on the scores assigned by the interviewees, the Maintainability indices of various pre and post-occupancy practices or features are computed thereupon. A ranking order can be derived from these maintainability indices to sort out those critical factors. Statistical analysis is eventually conducted to observe the score distribution.

Relative Importance Index

In light of maintainability, the relative ranking of the proposed pre and post-occupancy practices or features from are determined quantitatively using the scores provided by the interviewees. The scores are then transformed to importance indices based on the following formula (Kometa *et al.*, 1994; Tam *et al.*, 2000)

$$\text{Relative Importance Index} = \sum \mathrm{w} / A \; x \; N$$

where w is the weighting given to each choice (i.e. a particular choice of construction system) by the interviewee, ranging from 1 to 5 in this study where '1' is the least important or significant and '5' the most important or significant, *A* is the highest weight which is 5 in this study and *N* is the total number of samples. Therefore, the calculated Relative Importance Indices ranges from 0 to 1.

The above formula is modified by Lam *et al.* (2006) to a more user-friendly way as:

Relative Importance Index = $\sum$ (Individual Score of a Particular Item x Frequency of that Score) / (Number of Samples x Maximum Score)

Statistical Analysis

To depict a clearer picture of the results, in addition to the relative importance scale, the percentage of respondents scoring 0, less than 3, 3 and above 3 are calculated for three reasons. First, to distinguish between two items or more which have the same Maintainability index. Since the interviewees are allowed to delete any irrelevant items, the second reason is to check for relevancy of the items on the subject. The higher the rate of '0' recorded, the less the relevancy of an item to maintainability. Third, the analysed result can show the distribution of the scores.

Factor Analysis

Numerous points linked with maintainability are identified from literature at the moment, *ergo*, the multivariate technique of Factor Analysis is employed to extract principal factors from scattered data. Theoretically, the extracted principal factor should demonstrate relationship with sets of interrelated variables. As a means to reduce and consolidate data, interdependence of all variables are analysed and considered concurrently. (Lam *et al.*, 2006; Hair, *et al.*, 1998) A number of statistical techniques are incorporated in Factor Analysis with minimum loss of information for simplifying complex sets of data (Kline, 1994). To perform Factor Analysis, Statistical Package for Social Science (SPSS) is used. The collected data (i.e. scores assigned by the interviewees) are input into the software package and the factors are grouped into a smaller number of significant factors.

3.3.2 Survey on the Maintainability of Different Construction Systems

3.3.2.1 Objective

In clothes washing clothing materials are confined to certain cleaning methods. Business suits, for example, should be dry cleaned. Partially inspired by this observation, it is therefore suggested that construction systems will inevitably impose influences on building maintainability. Thus, the second part is to investigate commonly used construction systems in local construction industry from maintainability perspectives.

3.3.2.2 Methodology

Commonly used construction systems in local construction industry are again identified through reviewing literatures, however, they are mostly texts focused in local construction methods and materials. In view of actual maintenance operations, the construction systems are classified into structural frame, slab and roof and building envelope. The items listed in the questionnaire are shown in Figure 3.3.

Similarly, interviewees are required to indicate their choice in terms of maintainability in 5-point Likert Scale. By the same token, ‘5’ indicates very high contribution towards maintainability, and vice versa. Interviewees are encouraged to introduce any other construction systems which are not included in the questionnaire and space is provided in the questionnaire. All questions raised by interviewees on the questions will be answered and explained. A sample of this questionnaire is exhibited in Appendix B.

3.3.2.3 Data Analysis

The relative ranking of these construction systems from maintainability perspectives are determined using the scores provided by the interviewees. The scores are transformed to importance indices using the following formula which has been discussed in Section 3.3.1.3

$$\text{Relative Importance Index} = \sum \text{w} / A \, x \, N$$

To facilitate the calculation process in working out the indices, the following formula which is more convenient to use is applied:

Relative Importance Index = $\sum$ (Individual Score of a Particular Item x Frequency of that Score) / (Number of Samples x Maximum Score)

The collected data is further analysed. The percentage of interviewees scoring less than 3, 3 and above 3 is calculated accordingly to rank and distinguish two or more items which share the same importance index.

As a result, a higher Relative Importance Index indicates a certain construction system is more maintainable. In the meantime, the percentage of score chosen will be given.

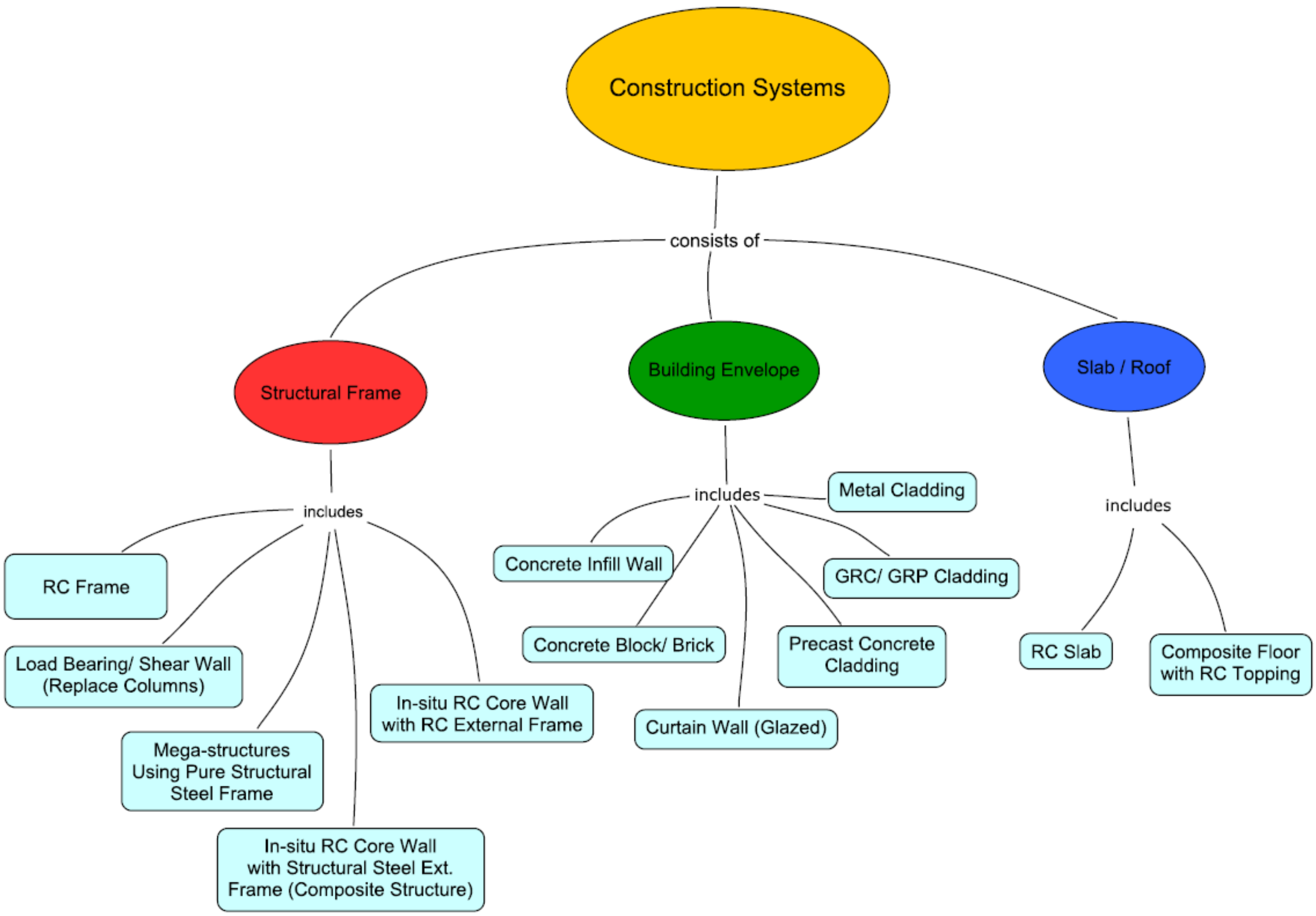


Figure 3.3 Commonly used construction systems in local construction industry

3.3.3 Survey on the Effects of Finishing Systems on Building Maintainability and Importance of Among These Systems

3.3.3.1 Objective

Finishing systems, *idem*, are believed to have implication on building maintainability. Hence, the objective of this survey is to determine the relative maintainability of finishing systems which are commonly used in Hong Kong. With this information, the Relative Importance Index of a particular finishing system can be established. In addition, views from the interviewees are collected about ratings of finishes applied at different locations in light of maintainability.

3.3.3.2 Methodology

During the design process of the questionnaire, above all, sites within buildings where finishes are applied are first located followed by identification of finishing systems which are commonly used in Hong Kong from literatures. The five locations include internal ceilings, internal walls, internal floors, external walls and roof. A total number of 36 finishes applied at these 5 locations was identified. They are tabulated and shown in Table 3.1.

Common Finishing Systems Applied at Different Locations of a Building	
Internal Ceiling Finishes	• False Ceiling – Mineral Fibres • Metal Suspended Ceiling • Dry Lining Ceiling • Plaster and Painting • Wall Paper
Internal Wall Finishes	• Wall Tiles • Marble and Granite • Timber • Glass • Plaster and Painting • Fairface Concrete • Wall Paper
Internal Floor Finishes	• Granolithic Finish • Terrazzo • Ceramic Tiles • Quarry Tiles • Concrete Tiles • Flexible PVC • Carpet • Marble or Granite Slabs • Timber Boarding • Raised Flooring

Table 3.1 Commonly used Finishing Systems in the local construction industry (to be cont'd)

(Cont'd)

Common Finishing Systems Applied at Different Locations of a Building	
External Wall	• Ceramic/ Mosaic Tiles • Marble and Granite • Traditional Masonry • Fairface Concrete • Plaster and Painting • Timber • Metal Cladding • Glass (in form curtain wall)
Roofing	• Tiles on Asphalt Roofing • Tiles on Bitumen Felt-Built-Up Roofing • Tiles on Bituminous Emulsion Roofing • Corrugated Steel Sheet/ Aluminum • Rolled Copper Sheet/ Strip/ Foil • Milled Sheet

Table 3.1 Commonly used Finishing Systems in the local construction industry

In this part, interviewees are required to indicate their views on finishes upon their relative maintainability in which these finishes are arranged in five tables according to the location where they are applied.

Once again, the 5-point Likert Scale is used where '5' indicates a particular finishing system with very high contribution towards maintainability and in the other way round, '1' refers to a finishing system that has very low contribution towards maintainability. Space was provided in each of the aforesaid tables for the interviewees to add other finishing systems which were not mentioned.

Having completed the previous part, interviewees are asked to determine the relative importance of maintainability of finishing systems applied in different locations of a building in whole number percentage, that is, the five locations mentioned above. A sample of the questionnaire of this part is shown in Appendix C.

3.3.3.3 Data Analysis

The Relative Importance Index method mentioned in Section 3.3.1.3 and 3.3.2.3 is adopted again for analyzing the survey result. The Relative Importance Index, or Maintainability index of Finishing Systems applied at different location is computed using the following formula:

Relative Importance Index = Σ (Individual Score of a Particular Item x Frequency of that Score) / (Number of Samples x Maximum Score)

A higher Relative Importance Index indicates a certain finishing system applied at a specific location is more maintainable. The percentage of distribution of scores is calculated in a similar way as stated in Section 3.3.1.3. Through comparing the magnitude of the Relative Importance Indices, a ranking order can be worked out.

3.3.4 Survey on the Features in Building Services Systems Affecting Maintainability

3.3.4.1 Objective

In the forth part of the questionnaire survey, this part serves to inquire the interviewees their views of the features in building services system that contribute towards good maintainability. After all, the Relative Importance Indices of these features can be determined.

3.3.4.2 Methodology

With prior literature review focused on maintainability issues in engineering systems, maintainable features were sorted out in 9 key directions (Figure 3.4) which consist of 19 points. The interviewees were requested to rank them to find out the Relative Importance Indices, likewise, the 5-point likert scale was used with ‘5’ indicating the highest importance and ‘1’ indicating the least. A sample of the survey question of this part is attached in Appendix D.

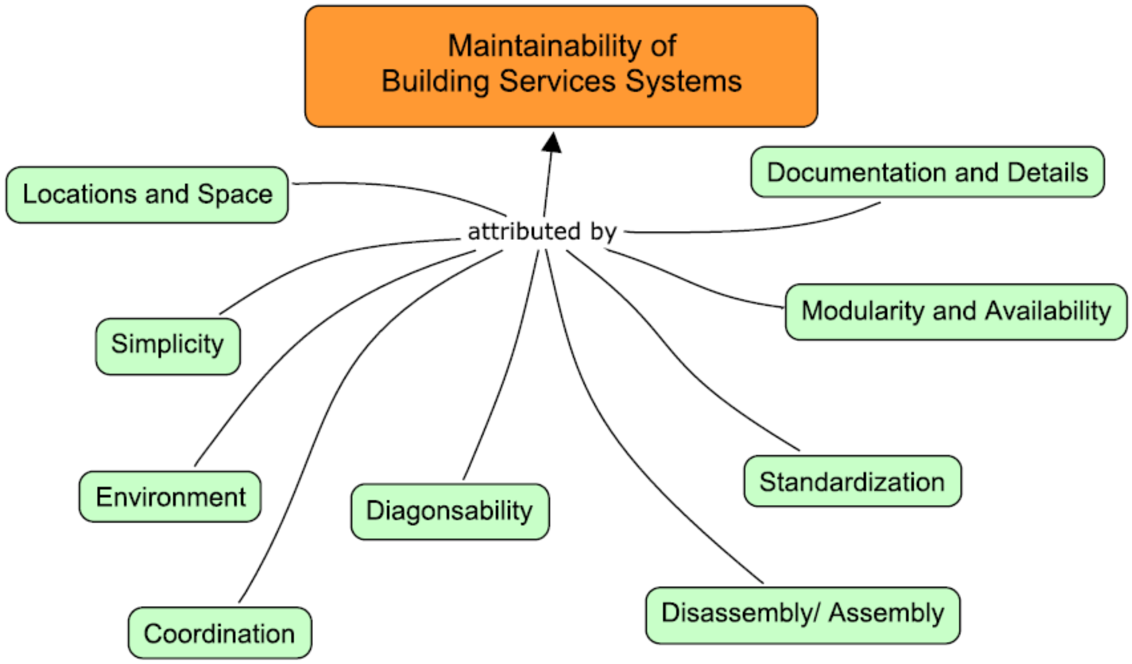


Figure 3.4 9 Key attributes of a maintainable system in engineering

3.3.4.3 Data Analysis

The method of Relative Importance Index mentioned in Section 3.3.3.1 is used to compute the relative importance of maintainability attributes in building services systems. Percentage showing the distribution of scores will be given through statistical analysis. A high Relative Importance Index implies an attribute in building services systems is more significant in terms of maintainability.

3.3.5 Survey on the Site/ Locational Factors Affecting Maintainability

3.3.5.1 Objective

The aim of this module seeks to quest for interviewees' views and rankings of site or locational factors affecting maintainability with a goal to work out the Relative Importance Indices of these factors.

3.3.5.2 Methodology

In like manner, 21 site and locational factors are extracted from the findings in previous literature review. Interviewees are requested to rate theses factors with respect to building maintainability and the 5-point likert scale is used, with '5' indicating a particular factor which has very high contribution towards maintainability and '1' indicates very low contribution. Space is provided at the end of this part for the interviewees to add any missing site or locational factors or express their opinions. Questions are welcomed and will be answered by the interviews. A survey question sample is attached in Appendix E.

3.3.5.3 Analysis

The Relative Importance Index method is adopted to derive the Maintainability index of a particular site/ location factor. Details of the method have been discussed in Section 3.3.1.3 of this chapter. The distribution of scores is analysed and provided too.

3.3.6 Survey on the Weightings amongst Components Contributing Towards the Overall Maintainability

3.3.6.1 Objective

Having established the Relative Importance Indices of individual items in former parts, the objective of this section is to weight the significance of different components in the assessment framework in respective of building maintainability.

3.3.6.2 Methodology

With a view to weight the aforementioned components from part 1 to part 5, which include pre and post maintainable measures (part 1), structural system, slab system and building envelope system (part 2), finishing systems (part 3), building services system (part 4) and site/ locational factors (part5), interviewees are requested to write down their relative importance in percentage with regard to maintainability. They are free to add any remark in the space provided and raised any questions. A sample of the survey question is attached in Appendix F.

3.4 Qualitative Module

3.4.1 Objective

Along with the quantitative module, the objective of this section is to polish the proposed assessment framework with the aid of opinions from the interviewees. Meanwhile, it also probes into the issue of building maintainability and maintenance in local construction industry to review the current state of art in the two aspects to capture the full picture of maintainability.

3.4.2 Methodology

The general direction of this part is for the interviewees to express freely on the subject of maintainability. The interviewees are moved through inviting them to explain some of the choices in the questionnaire. Some open-ended questions are raised subsequently. On the whole, interviewees are invited to speak whatever they considered important or share any experiences relevant to the subject without being restrained by the questions.

- ✓ From your experience in the industry, how do you interpret 'maintainability'?
- ✓ What are the difficulties encountered in carrying out maintenance?
- ✓ What are the causes of the difficult maintenance?
- ✓ What are the reasons that hinder buildings from achieving good maintainability?
- ✓ Does the choice of construction systems and materials matter on the future maintainability?
- ✓ Parties in the project team have quite different sets of objectives, in this regard, how would you propose to achieve high level of maintainability?

3.5 Summary

The research methodology adopted for developing the Maintainability Assessment Model has been reported in depth in this chapter. Structured interviews with experienced property managers and facility managers are carried out to obtain both quantitative and qualitative data. In the quantitative module, surveys on 6 aspects in a building relating to maintainability are conducted to establish the Maintainability indices of individual items decide the weightings which represent the relative importance amongst components in the assessment model. Questions are raised at the same time during interviews. These questions are asked to refine and amend the assessment framework and useful for probing into issue of building maintenance and maintainability.

In the next chapter, the data and information obtained in qualitative module and quantitative module from the interviewees will be analysed and discussed.

CHAPTER 4 DATA ANALYSIS AND DISCUSSION OF FINDINGS

4.1 Introduction

This chapter introduces the findings from the structured interviews and thus discusses the analysed results. The research has been conducted in the fashion as described in Chapter 3, with the principal quantitative module which consists of 6 parts and the qualitative module to quest for information on the subject of maintainability and opinions for refining the assessment model. In the first instance, the background of the interviewees is reported. The Maintainability indices of pre and post-occupancy practices, construction systems, finishing systems, building services systems and site/ locational factors are then computed and presented accordingly. Further analyses are performed to review the distribution of scores by the interviewees. These results are attached in Appendix G to M. Followed by the quantitative module, collected comments and opinions on the subject and the assessment model are described in gist. In the end, a summary compiling the essentials of the chapter is given.

4.2 Profile of Interviewees

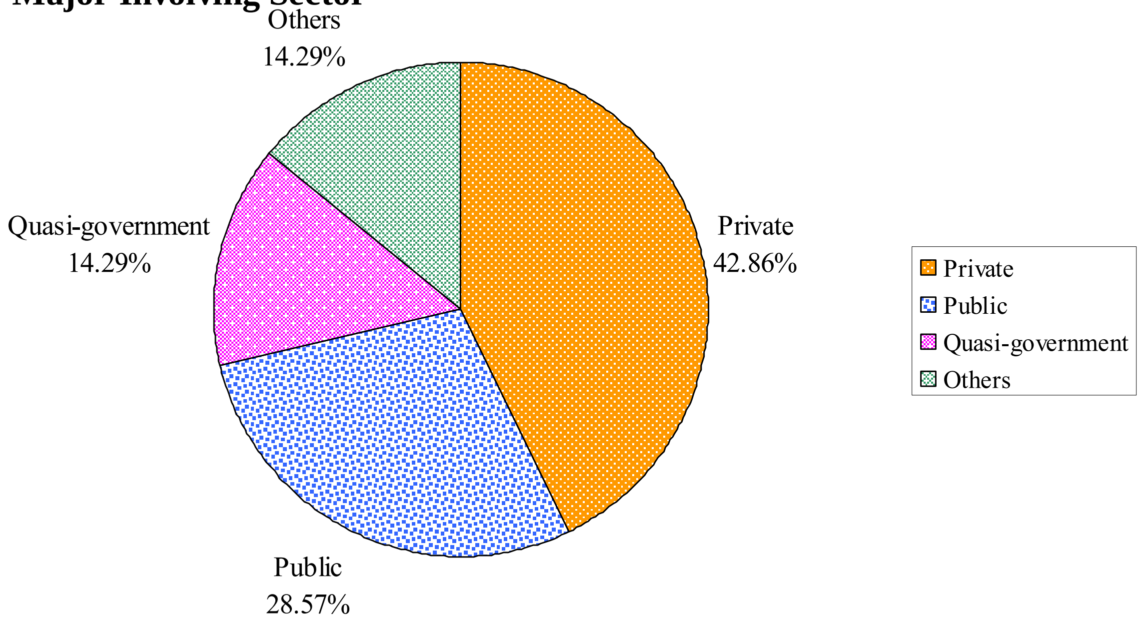
13 structured interviews were conducted in early 2008 with very experienced practitioners who involve in property management and building maintenance and hold senior positions in the industry as property managers or maintenance managers. In the absence of sufficient time and resources allowed for this research to interview all the involving parties in building development and management process, all the interviewees were within the target group as stated in Section 3.2.2.

Contact information of target interviewees were extracted from the information available in the web pages and publications of property management companies, consultancy and bodies, as well as relevant professional institutions, 27 invitations were made by facsimile or electronic mails, or both. Finally, 13 interviews were arranged successfully which accounts for 48.15% of the total invitations extended. The background of the interviewees is given in Table 4.1 and Figure 4.1

Sector	Practitioners Interviewed	No. of interviews	Set(s) of survey(s) received
Private	A director of a property development consultancy who also serves a relevant professional institution	1	1
Private	A director, a senior manager and a technical officer of a property management company	1	1
Private	A facility manager working in private sector who also serves a relevant professional institution	1	1
Private	A director in the property management department of a surveying consultancy	1	1
Private	A director and a technical manager of property management companies working for private sector clients	2	2
Private	A manager of a property management company who also serves a relevant professional institution	1	1
Public	A senior property manager in public sector who also serves a relevant professional institution	1	1
Public	A senior property services manager with major experience in managing government facilities	1	1
Public	A senior maintenance surveyor with major experience in maintaining housing developments	1	1
Public	A senior building surveyor who also serves a relevant professional institution	1	1
Quasi-government	A project manager working for a statutory body	1	1
Quasi-government	A general manager working for a statutory body	1	1

Table 4.1 Profile of the interviewees (survey received refers to the completed question set in quantitative module)

Major Involving Sector



Years of Experience

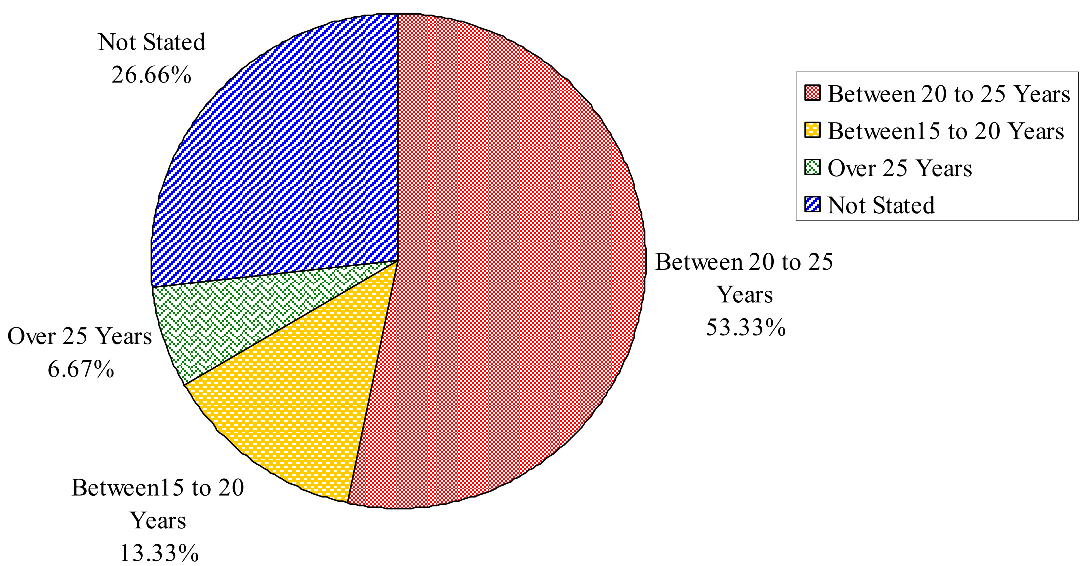


Figure 4.1 Background of the interviewees (Cont'd)

(Cont'd)

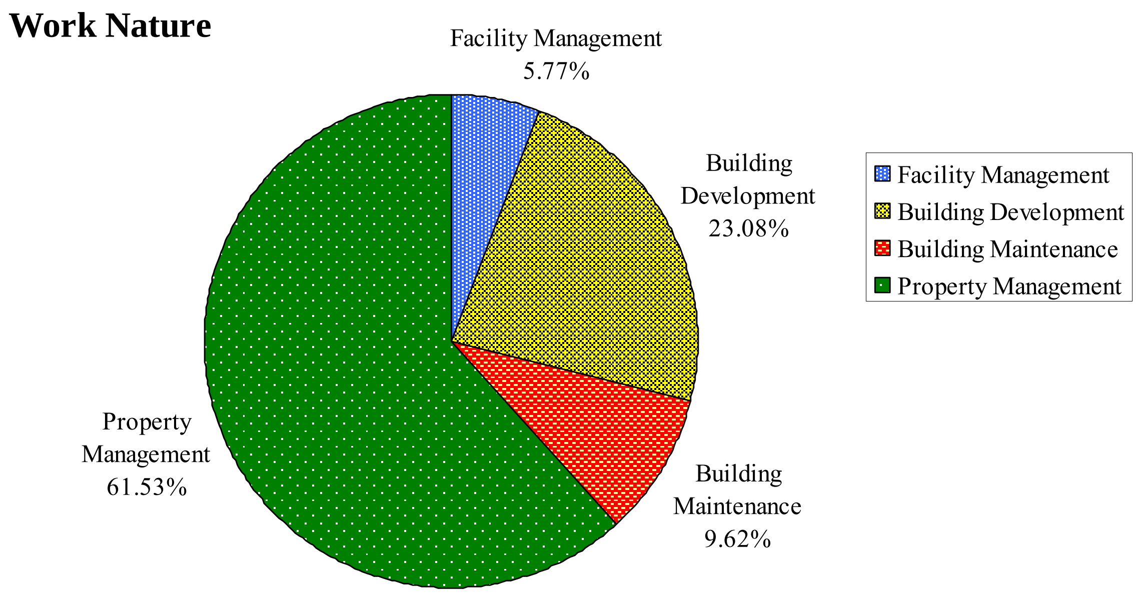


Figure 4.1 Background of the interviewees

The majority of the interviewees are working in the private sector, which accounts for 42.86%. About 29% and 14% of the interviewees are working in public and quasi-government organizations respectively. (note: 14.28% of the interviewees indicated that they work in more than one sector) Since the target interviewees are experienced practitioners in the field, they all have experience more than 15 years. More than a half of them have experience between 20 to 25 years (53.33%), one-eighth (13.33%) have experience between 15 to 20 years and 6.67% have more than 25 years. For the major experience in the field, 61.54% of the interviewees indicated property management as their major nature of work followed by building development (23.08%). To a lesser extent, maintenance and facility management accounts for 9.62% and 5.77% respectively.

4.3 Findings from the Quantitative Module

4.3.1 Findings from the Survey on the Pre and Post-occupancy Practices Affecting Maintainability

All the interviewees are requested to complete the 51 questions in this section at the outset and 13 valid samples are obtained. With these samples on hand, three operations can be undergone. Factor analysis is employed to simplify the collected data and generalize a list which serves as guideline to improve maintainability. Maintainability indices of various pre and post-occupancy practices or features are calculated for future assessment of building maintainability and thus a ranking order can be derived from the maintainability indices to distinguish those factors which are highly critical to maintainability. Besides, statistics analysis is conducted to observe the distribution of scores. The purpose of such analysis is to differentiate the ranking of items which have the same Maintainability index. Percentage of interviewees scoring less than 3, 3 and greater than 3 in each question was calculated and given in Appendix G and H. Furthermore, percentage of zero score was provided solely in this section. A zero score render a particular item irrelevant to maintainability.

Pre-occupancy Practices or Features

The Maintainability Indices of the 39 pre-occupancy practices or features is provided in Table 4.4. They are arranged according to their relative importance under respective headings. In the meantime, the headings are ranked as well using the corresponding mean index. From the result, the relative importance indices ranged from 0.477 to 0.969. The top and bottom 3 headings and items are given in Table 4.2 and Table 4.3 accordingly.

In general, it is noted that those practices with high Maintainability index are characterized by providing adequate access (e.g. adequate provision of access for the execution of maintenance tasks (both routine and periodic) (M_{IMP} = 0.969), designing adequate access for purpose of inspection (M_{IMP} = 0.923) and allowing sufficient working space for labour and plant (M_{IMP} = 0.862)), enabling safe maintenance (e.g. designing for safe maintenance at height, underground or in confined space (M_{IMP} = 0.862), components sizes and weights of materials and components are safe for workers to handle using commonly available plants (M_{IMP} = 0.738)) and awareness in maintainability by the involving parties (e.g. participation of experienced maintenance manager during the design process (M_{IMP} = 0.877), designers have access to the information, specifications and data about the performance of materials (M_{IMP} = 0.831) and designers or architects have received training in maintainability (M_{IMP} = 0.831)).

Rank	Pre-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
1	Diagnosability	0.885
2	Personnel	0.810
3	Design Layout	0.778
:		
:		
:		
13	Prefabrication	0.631
14	Project Management and Procurement	0.588
15	Innovation	0.523

Table 4.2 Tabulated summary of top-3 and bottom-3 practices or features (in headings)

In the midst, simplicity and flexibility in design (e.g. allowing modular layout of components (M_{IMP} = 0.769), design which enables the use of readily available alternative materials or components of similar performance, costs and appearance (M_{IMP} = 0.769)) and availability of maintenance resources are essential too (e.g. designers have access to the information, specifications and data about the performance of materials and components (M_{IMP} = 0.831), considering the availability of maintenance equipment right from the design stage, application of automatic machines (M_{IMP} = 0.831), a clear design brief from the client in maintenance performance (M_{IMP} = 0.769) and designing for the optimum use of maintenance equipment and plant (M_{IMP} = 0.769)).

In contrast with the suggestion to incorporate revolutionary and new features into buildings to enhance the built-environment, innovations are unfavourable in view of maintainability. No alternatives are readily available and comparatively more difficult to maintain as maintenance staffs are unfamiliar to these features. 'Institutional arrangement' is found to have little help in enhancing maintainability too. (Table 4.2 and 4.3)

Rank	Pre-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
1	Adequate provision of access for the execution of maintenance tasks (both routine and periodic)	0.969
2	Designing adequate access for purpose of inspection	0.923
3	Design has taken full account of climatic factors in choosing materials	0.908
: : :		
13	Design to allow for innovative construction techniques and use of innovative materials which are well tested	0.523
14	Extraordinary longer Defects Liability Period	0.477
15	Using the Design and Build Procurement System	0.477

Table 4.3 Tabulated summary of top-3 and bottom-3 practices or features

Rank	Pre-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
1	**Diagnosability**	**0.885**
	• Designing adequate access for purpose of inspection	0.923
	• The choice of materials and components which enable diagnosis to be carried out in an inexpensive and time-saving manner using handy methods and shows immediate result	0.846
2	**Personnel**	**0.810**
	• Designers have access to the information, specifications and data about the performance of materials and components	0.831
	• Designers or architects have received training in maintainability	0.831
	• A clear design brief from the client in maintenance performance	0.769
3	**Design Layout**	**0.778**
	• Adequate provision of access for the execution of maintenance tasks (both routine and periodic)	0.969
	• Allowing sufficient working space for labour and plant	0.862
	• Designing for safe maintenance at height, underground or in confined space	0.862
	• Designing for minimum maintenance at height, underground or in confined space	0.738
	• Avoid designing permanent fixations	0.462
4	**Involvement of Property Manager or Maintenance Manager**	**0.754**
	• Participation of experienced maintenance manager during the design process	0.877

Table 4.4 The ranking and Maintainability indices of pre-occupancy practices (Cont'd)

(Cont'd)

Rank	Pre-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
	• Future maintenance manger involves in the supervision of construction works to facilitate future maintenance tasks	0.631
5	**Materials**	**0.751**
	• Design has taken full account of climatic factors in choosing materials	0.908
	• Designers have taken full account in and balanced the locality, economics and building technique in choosing material	0.769
	• Choosing materials which require minimum maintenance	0.754
	• Using materials which are available during the life of the building	0.692
	• Avoid specifying materials which need complete replacement	0.631
6	**Flexibility**	**0.746**
	• Design which enables the use of readily available alternative materials or components of similar performance, costs and appearance	0.769
	• Designing for interchangeability	0.723
7	**Standardization**	**0.742**
	• Allowing modular layout of components	0.769
	• Use of standard details with lots of repetition such that relatively low skill level is required	0.754
	• Allowing a high degree of standardization and repetition of components used but review the standards regularly	0.723

Table 4.4 The ranking and maintainability indices of pre-occupancy practices (Cont'd)

(Cont'd)

Rank	Pre-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
	• Uncomplicated geometry, layout and shape of components	0.723
8	**Maintenance Plants and Equipments**	**0.727**
	• Considering the availability of maintenance equipment right from the design stage, Application of automatic machines	0.831
	• Designing for the optimum use of maintenance equipment and plant	0.769
	• Sizes and weights of materials and components are safe for workers to handle using commonly available plants	0.738
	• Maximize the use of automatic machines as daily maintenance equipments	0.569
9	**Disassembly/ assembly, Installation**	**0.708**
	• Allowing easy connection// interfacing between components	0.708
	• Allowing easy installation without complicated fixings	0.708
10	**Other Resources**	**0.708**
	• Material manual about the durability of materials, routine maintenance and performance	0.708
11	**Weather**	**0.700**
	• Design option which will minimize the effect of weather on maintenance	0.754
	• Design to allow maintenance to be deferred until desirable weather or rescheduled to accommodate planned maintenance	0.646

Table 4.4 The ranking and maintainability indices of pre-occupancy practices (Cont'd)

(Cont'd)

Rank	Pre-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
12	**Specification and Detailing**	**0.677**
	• Specifying in the contract document as detail as possible the necessary construction materials and construction methods	0.677
13	**Prefabrication**	**0.631**
	• Choice of materials/ components allowing prefabrication of components off site	0.631
14	**Project Management and Procurement**	**0.588**
	• Evaluating the design scheme with life-cycle costing technique	0.754
	• Enhancing the working relationship between consultant, contractor and client	0.646
	• Extraordinarily longer Defects Liability Period	0.477
	• Using the Design and Build Procurement System	0.477
15	**Innovations**	**0.523**
	• Design to allow for innovative construction techniques and use of innovative materials which are well tested	0.523

Table 4.4 The ranking and Maintainability indices of pre-occupancy practices

Post-occupancy Practices or Features

There are 12 questions regarding post-occupancy practices or features on maintainability. The results are subsequently ranked according to their respective Maintainability indices. They are shown in Table 4.5. The Maintainability indices fluctuated less widely from 0.600 to 0.938 than that in the section of pre-occupancy measures.

The survey result showed that personnel (M_{IMP} = 0.900) and alteration (M_{IMP} = 0.877) are top ranked amongst the 4 headings whilst environmental considerations (M_{IMP} = 0.677) have notably lower importance towards maintainability. In token of pre-occupancy practices or features, again safety and awareness in maintainability supplemented by suitable resources are utterly most important in enhancing maintainability. Hence, the 4-top ranked practices are implementation of proper maintenance management programme (M_{IMP} = 0.938), proper routine and periodic maintenance (e.g. cleaning and repair) with records in log book (M_{IMP} = 0.908), with as-built drawings showing the accurate position of works (M_{IMP} = 0.908) and proficiency of staffs in carrying out maintenance works and diagnosis (M_{IMP} = 0.908) accordingly. In contrast, environmental concerns are believed to be less significant in maintainability (M_{IMP} = 0.667).

Rank	Post-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
1	**Personnel**	**0.900**
	• Proficiency of staffs in carrying out maintenance works and diagnosis	0.908
	• Providing a hazardous free environment for personnel to execute maintenance work, for example, precautionary measures for proximity of high voltage lines, no harmful gaseous content	0.892
2	**Alteration**	**0.877**
	• Avoid the presence of Unauthorized Building Works	0.877
3	**Management and Documentations**	**0.890**
	• Implementation of proper maintenance management programme	0.938
	• Proper routine and periodic maintenance (e.g. cleaning and repair) with records in log book	0.908
	• With as-built drawings showing the accurate position of works	0.908
	• Keeping coordinated drawings, manuals and maintenance handbook in custody by the property owner	0.877
	• Documentations (e.g. specifications, drawings, etc) in custody are detailed, unambiguous, misunderstanding free and the most updated	0.862
	• Operational and maintenance guidelines with the information on repair and replacement procedures	0.846

Table 4.5 The ranking and Maintainability indices of post-occupancy practices (Cont'd)

(Cont'd)

Rank	Post-construction Practices or Features Affecting Maintainability	Maintainability Index (M_{IMP})
4	**Environmental Consideration**	**0.667**
	Causing less environmental nuisance (e.g. noise, vibration, waste water, chemical waste and dust) to the surroundings in the course of maintenance	0.785
	Optimizing the mix of offsite work and onsite work by the maintenance manager	0.615
	Allowing less wet trades in situ	0.600

Table 4.5 The ranking and Maintainability indices of post-occupancy practices

Results from Factor Analysis

Resting on the 13 valid samples obtained, attempts have been made to extract the principal Maintainability Factors with Varimax rotation (Fig 4.2) to reduce and group various factors under a smaller number of principal factors. It is a technique in Factor Analysis to maintain independence among the factors. It is, however, failed to achieve the intended result after undergoing this analysis, that is, unable to group scattered factors into specific principal factors.

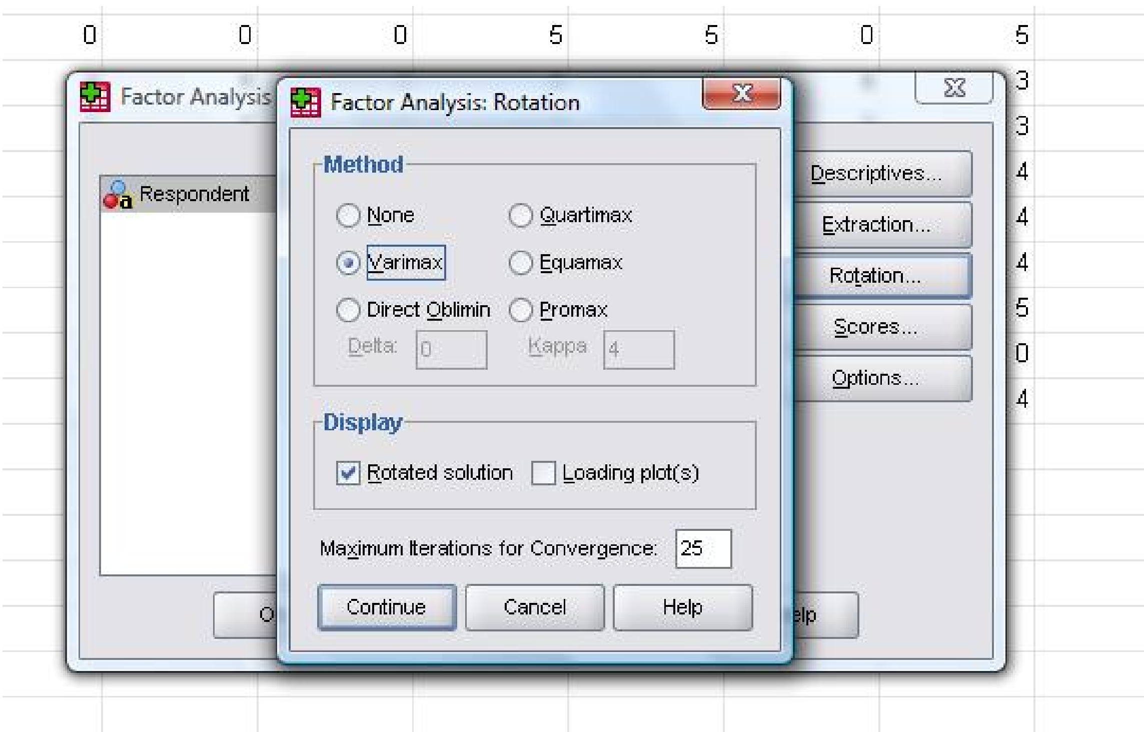


Figure 4.2 Varimax rotation technique in SPSS

The chief reason accountable for such failure is the small sample size. Notwithstanding the fact that all the interviewees are regarded as representative respondents in the field of property management and building maintenance, it is believed that absolute sample size is above all the most important in Factor Analysis (Guadagnoli and Velicer, 1988). Nevertheless, there isn't any wide accepted guideline for the minimum sample size required to conduct Factor Analysis. Some suggested sample size to number of variables ratio range from 2:1 through 20:1 can be a criterion in determining the size. In general, the suggestion that the absolute sample should exceed 100 observations is raised. Field (2005) reviewed many suggestions regarding the sample size issue and concluded that the optimum sample size depends on many things. Over 300 cases are probably adequate but communalities after extraction should probably be above 0.5, whereas Guadagnoli and Velicer (1998) suggested that 100 to 200 observations suffice for reliable result. Absolute sample size is more important in working out a stable solution than the aforesaid ratio. Despite the unsuccessful attempt, the Factor Analysis result is attached in Appendix I.

4.3.2 Findings from the Survey on the Maintainability of Different Construction Systems

In the course of interviews, there were lively discussions on the issue whether building maintainability is affected by the construction systems used. Diverging views were aired and the findings are going to be discussed in depth in the qualitative module in Section 4.4.2. To return to the theme, 4 out of 13 interviewees believed that the construction system itself was irrelevant to or had little impact on the overall building maintainability, which accounts for 30.77% of the total interviewees. Hence, 9 valid samples were received and used to compute the relative importance index (please refer to Section 3.3.2.3 for the methodology). The calculated relative importance indices of different construction systems are given in Table 4.6. The result were further analysed to observe the score distribution, which is shown in Appendix J.

From the resulting relative importance indices, different construction systems deviate within a narrow range from 0.622 to 0.778. It is therefore have a few suggestions on such finding. First, it is inferred that different construction systems exhibit almost indifferent maintainability. This result confirmed with the views of those who thought that construction systems of a building had little implication on maintainability because they are more or less similar to maintain. According to the interviewees, not the construction method or system but the way it is built affects maintainability, for example, the design layout. To a lesser extent, another possible reason may due to the research limitation. Only simple ranking of construction systems is possible in this stage on account of the resources and then the survey questions may be over-simplified. Pairwise comparison should be made amongst different construction system with respect to aspects which are identified and ranked in Section 4.3.1. Resting on the comments added by the interviewees, nevertheless, it is believed that the former reason prevails.

Construction Systems	Maintainability Index
Structural Frame	**(M_{ISF})**
In-situ RC Core Wall with RC External Frame	0.711
In-situ RC Core Wall with Structural Steel External Frame (i.e. Composite Structure)	0.711
Mega-structures using Pure Structural Steel Frame	0.711
RC Frame	0.689
Load Bearing or Shear Walls that Replace Columns	0.622
Slab and Roof	**(M_{ISL})**
RC Slab	0.711
Composite Floor with RC Topping	0.667
Building Envelope	**(M_{ISE})**
Concrete Block/ Concrete Brick	0.778
Curtain Wall (Glazed)	0.778
Concrete Infill Wall	0.711
Precast Concrete Cladding	0.711
Metal Cladding	0.711
GRC/ GRP Cladding	0.689

Table 4.6 Maintainability indices and the ranking of different construction systems

4.3.3 Findings from the Survey on Maintainability of Different Finishing Systems

In this survey, all except 2 interviewees agreed that building maintainability is affected by the finishing systems used. Additional information regarding this issue is reported in Section 4.4.3. Base on the 11 valid samples, the relative importance of different finishing systems applied at internal ceiling, internal wall, internal floor, external wall and roofing is calculated using the relative importance index method (please refer to Section 3.3.2.3). A ranking order is obtained thereafter with further analysis.

The data were further analysed and percentage of respondents scoring less than 3, 3 and greater than 3 were calculated. The result showing the distribution of scores together with the standard deviation is shown in Appendix K. By comparing the scores distribution, equal Maintainability indices can be distinguished and ranked in accordance with percentage of respondents scoring greater than 3.

Table 4.7 shows the ranking of different finishing systems. It can be seen that Metal Suspended Ceiling (M_{IIC} = 0.836), Wall Tiles (M_{IIW} = 0.745), Marble or Granite Slabs (M_{IIF} = 0.691), Glass (M_{IEW} = 0.709) and Tiles on Bitumen Felt Built-Up Roofing (M_{IRF} = 0.673) were top ranked among the finishing systems in their respective applied locations. On the contrary, Wall Paper applied at both internal ceilings (M_{IIC} = 0.382) and internal walls (M_{IIW} = 0.382), Carpet (M_{IIF} = 0.491), Timber (M_{IEW} = 0.309) and Milled Sheet (M_{IRF} = 0.491) are regarded as the least maintainable finishing systems. The top ranked finishing systems are characterized by enabling easy cleaning, repairing, fixing and replacing.

On the other hand, interviewees were asked to determine the relative importance of maintainability of finishing systems applied in different locations in whole number percentage. 10 valid samples were obtained and the table showing the results is given in Table 4.8.

Locations	Finishing Systems	Maintainability Index
Internal Ceilings (M_{IIC})	• Metal Suspended Ceiling (e.g. Aluminum Panels, Egg Crate)	0.836
	• False Ceiling (Mineral Fibre)	0.618
	• Plaster and Painting	0.618
	• Dry lining Ceiling (e.g. plasterboard)	0.455
	• Wall Paper	0.382
Internal Wall (M_{IIW})	• Wall Tiles	0.745
	• Marble and Granite	0.709
	• Glass	0.636
	• Plaster and Painting	0.564
	• Timber (e.g. Plywood, Plaster-board)	0.491
	• Fairface Concrete	0.473
	• Wall Paper	0.382
Internal Floors (M_{IIF})	• Marble or Granite Slabs	0.691
	• Raised Flooring	0.691
	• Ceramic Tiles	0.673
	• Quarry Tiles	0.582
	• Terrazzo	0.545
	• Concrete Tiles	0.545
	• Flexible PVC	0.545
	• Timber Boarding	0.527
	• Granolithic Finish	0.509
	• Carpet	0.491
External Wall (M_{IEW})	• Glass (in form of curtain wall or other)	0.709
	• Metal Cladding	0.691
	• Marble and Granite	0.655
	• Ceramic/ Mosaic Tiles	0.636
	• Traditional Masonry	0.618

Table 4.7 Maintainability index and the ranking of different finishing systems (Cont'd)

(Cont'd)

Locations	Finishing Systems	Maintainability Index
External Wall	• Plaster and Painting	0.564
	• Fairface Concrete	0.509
	• Timber	0.309
Roof (M_{IRF})	• Tiles on Bitumen Felt Built-Up Roofing	0.673
	• Corrugated Steel Sheet/ Aluminum	0.618
	• Tiles on Asphalt Roofing	0.582
	• Tiles on Bituminous Emulsion Roofing	0.582
	• Rolled Copper Sheet/ Strip/ Foil	0.491
	• Milled Sheet	0.491

Table 4.7 Maintainability index and the ranking of different finishing systems (Cont'd)

Locations of Finishes	Averaged Maintainability Weightings of Different Finishing Locations
Internal Walls	20%
Internal Floors	20%
Internal Ceilings	18%
External Walls	26%
Roof	16%
Total:	100%

Table 4.8 Averaged Maintainability Weighting of Different Finishing Locations

4.3.4 Findings from the Survey on the Building Services Features Affecting Maintainability

In collecting the views and ranking on the relative importance of building services features on maintainability, 12 valid samples were received from the interviewees. The relative importance of different features in building services systems affecting maintainability was calculated in the way as mentioned in Section 3.3.4.3. Besides, a ranking order of the 9 key maintainability attributes identified (Fig 3.4) was derived. The overall index of a key attribute was calculated from the relative importance indices of sub-attributes, for example, location and space. A mean index of 0.892 of is calculated from its sub-attributes, ease of access (M_{IBS} = 0.933), adequate headroom for the sale of maintenance (M_{IBS} = 0.900), placing components in a suitable space and location (M_{IBS} = 0.867) and good layout of equipment in plant rooms (M_{IBS} = 0.867), that is (0.933 + 0.900 + 0.867 + 0.867) / 4.

Table 4.9 shows the Maintainability index of a particular feature in building services systems and the ranking order of the key attributes and sub-attributes. The result showing the distribution of scores with the standard deviation is shown in Appendix L.

From the result, disassembly/ assembly (M_{IBS} = 0.917), location and space (M_{IBS} = 0.892) and documentation and details (M_{IBS} = 0.886) are considered as the three most importance attributes affecting the maintainability of building services systems. Unlike building fabrics which comparatively require less maintenance with longer life-cycle, building services systems require more frequent maintenance such as adjustments and servicing to avoid system breakdown and hence interruption of service. A high degree of disassembly and assembly enables technical officers to carry out maintenance tasks more efficiently. Adequate access and documentations are equally important to facilitate maintenance in this respect. Other key attributes, per contra, are also very significant as shown in the result as Maintainability index of the key attributes ranged from 0.792 to 0.917.

Rank	Maintainable Features in Building Services Systems	Maintainability Index (M_{IBS})
1	**Disassembly/ Assembly**	**0.917**
	• Adopting systems which enable easy opening, fastening of parts and components	0.917
2	**Location and Space**	**0.892**
	• Ease of access	0.933
	• Adequate headroom for the sake of maintenance (e.g. replacement, inspection)	0.900
	• Placing components and equipments in a suitable space and location (e.g. avoid locating wet pipes over electrical installation, place bulky items on ground level)	0.867
	• Good layout of equipment in plant rooms to maximize the utilization of space and for maintenance to be carried out without difficulty	0.867
3	**Documentation and Details**	**0.886**
	• Operational and maintenance guidelines	0.933
	• Keeping log books with regular update for maintenance	0.917
	• Adequate installation details of the systems (e.g. penetration details, embedment details and details of supports)	0.883
	• Keeping the details of the systems	0.867
	• Trace of actual location of services system in as-built drawings/ photographs	0.867
	• Clear cable management and identification	0.850

Table 4.9 Maintainability index and the ranking of features in Building Services Systems (Cont'd)

(Cont'd)

Rank	Maintainable Features in Building Services Systems	Maintainability Index (M_{IBS})
4	**Environment**	**0.825**
	• Hazardous free environment for maintenance work	0.867
	• Minimal requirement of hoisting of parts, or adequate provision for temporary cranage	0.783
5	**Standardization**	**0.817**
	• Use of standard and universal components inside the system	0.817
6	**Diagonsability**	**0.808**
	• Provision of monitoring system for proper operation	0.817
	• Building services adopted with high diagonsability such that ordinary staffs can report the potential failure	0.800
7	**Simplicity**	**0.800**
	• Equilibrium between minimal replacement and minimum number of components/ assemblies	0.800
8	**Coordination**	**0.800**
	• Coordination between services systems and building systems	0.800
9	**Modularity and Availability**	**0.792**
	• Equipment design which enables only the failed parts to be repaired/ replaced	0.800
	• Parts or compatible replacements are always available within the life of systems	0.783

Table 4.9 Maintainability index and the ranking of features in Building Services Systems

4.3.5 Findings from the Survey on the Site or Locational Factors Affecting Maintainability

As already stated, the aim of this part is to work out the relative importance of site or locational factors. Upon the received 11 valid samples, the collected data are computed using the Relative Importance Method as stated in Section 3.3.5.3. In a similar way, a mean index of each of the 6 headings is calculated and hence the factors are ranked in accordance with their significance. The ranked result is given in Table 4.10 including their respective Maintainability index. Meanwhile, the distribution of scores in this survey is given in Appendix M.

In this survey, the interviewees rated underground maintenance (M_{ISS} = 0.864) as the most significant factors affecting building maintainability and access (M_{ISS} = 0.800) being the second. Definitely, underground facilitates are more difficult to maintain and more liable to safety hazards, whereas sufficient access are necessary for personnel to execute maintenance tasks with ease safely, entry and exit of plants and equipment to and from the points that require maintenance. In the eyes of the interviewees, hazard-free environment (M_{ISS} = 0.736) provided for execution of maintenance tasks was essential too. For the rest of the factors, preservation (M_{ISS} = 0.682), surrounding environment (M_{ISS} = 0.655) and restrictions on the execution of maintenance tasks (M_{ISS} = 0.655) were less important towards the subject of maintainability. Comparing this part with building services systems, the interviewees believed that site/ locational factors had less implication on maintainability. Maintainability indices here ranged from 0.655 to 0.864, whilst for building services systems the figures were notably higher, from 0.792 to 0.917. Furthermore, this suggestion was also confirmed in the coming part in Section 4.3.6 describing the weightings of maintainability components where the weight of building services systems in the model is also significantly higher than that of site/ locational factors.

Rank	Site/ Locational Factors	Maintainability Index (M_{ISS})
1	**Underground Maintenance**	**0.864**
	Adequate considerations incorporated into design to minimize design faults underground (e.g. overcoming potential problems of water ingress)	0.873
	Safety consideration or measures incorporated into design	0.854
2	**Access**	**0.800**
	Allowing for access and movement of any necessary plants with adequate turning radius	0.800
3	**Hazard-free Environment**	**0.736**
	No presence of hazardous substance inside the site e.g. asbestos	0.782
	Potentially hazardous establishments near the building, e.g. underground cable or gas/ petrol storage	0.691
4	**Preservation**	**0.682**
	Preservation of trees, monuments, etc within the building	0.691
	Preservation of trees, monuments, etc adjacent to the building	0.673
5	**Surrounding Environment**	**0.655**
	• Adequate working space for safe maintenance, building rehabilitation, etc	0.836
	• With access and exit roads for trucks and plants	0.782
	• No difficulties in setting up hoardings, scaffolding or shoring to adjacent buildings	0.709

Table 4.10 Maintainability index of Site/ Locational Factors (Cont'd)

(Cont'd)

Rank	Site/ Locational Factors	Maintainability Index (M_{ISS})
	• With temporary storage areas for maintenance works, repair, building rehabilitation, etc	0.709
	• Not abutting to vulnerable buildings/ structures such as old dilapidated buildings	0.673
	• Public utilities, e.g. gaseous pipes, electrical/ telecommunication cables etc, underneath the site	0.673
	• Not adjacent to water-containing areas e.g. sea, river, reservoir or lake	0.618
	• Buildings not on slope(s)	0.600
	• With open space	0.582
	• Not adjacent to occupied buildings/ structure	0.581
	• Not abutting pedestrian pavement(s)	0.545
	• Not abutting other construction site(s)	0.545
6	**Restrictions on the Executive of Maintenance Tasks**	**0.655**
	• Working hour restrictions	0.655
	• Construction sequence restrictions	0.655

Table 4.10 Maintainability index of Site/ Locational Factors

4.3.6 Findings from the Survey on the Weightings of Components in the Assessment Model

Having completed the previous 5 sections regarding building maintainability in various aspects, the interviewees were eventually requested to determine the relative importance of components in light of maintainability therein. 9 valid samples were collected and the result is shown in Table 4.11. Discussion and comments about this section is reported in Section 4.4 as well. All in all, the weightings adjusted to accommodate ‘Others’ for any other maintainable features or practices. Table 4.12 shows the final weightings to be incorporated in the assessment model.

Components	Averaged Maintainability Weightings of Different Finishing Locations
Structural System	7
Slab System	6
Building Envelope System	13
Finishing System	12
Pre and post occupancy measures	25
Building Services Systems	29
Site/ Locational Factors	8
Total:	100%

Table 4.11 Averaged maintainability weighting of components from the survey result

Components	Averaged Maintainability Weightings of Different Finishing Locations
Structural System	6
Slab System	5
Building Envelope System	12
Finishing System	11
Pre and post occupancy measures	23
Building Services Systems	26
Site/ Locational Factors	7
Others	10
Total:	100%

Table 4.12 Averaged maintainability weighting of components to be incorporated in the assessment model (after adjustment)

4.4 Qualitative Module

4.4.1 Pre and Post-occupancy Measures

In talking about the maintenance and maintainability issues in Hong Kong, the structure of the local construction and real estate industry can hardly be kept out of the picture. Broadly speaking, properties are developed either for sale or for rent. The majority of the interviewees were of the opinion that more consideration in future maintenance was given to the latter type (i.e. investment properties) simply because developers were under no obligation to maintain the properties in long-term for properties they had sold out. Very often subsidiary is opened for developing a project and closed down immediately when the project is completed to limit the liability of the parent company.

In contrast with properties for sale, building owners have to take good care of the investment properties to enhance their rental value. As such, participation of maintenance managers during design stage to give voices to future maintenance is more common in investment properties such as office developments, or public and institutional facilities for long-term use. Since the developers nowadays are more aware of their corporate image and consumer rights are emphasized, the situation that maintenance is overlooked and out of consideration has started to change in the past 10 years.

Dissimilar views were received for the timing of maintenance managers' participation during the design stage. Most interviewees thought that the opinions from maintenance manager would be useful only when the project had proceeded to detailed design because designs were still subject to extensive amendments in conceptual phase; nonetheless, still a minority of the interviewees stressed the importance of maintenance managers to step in right from the very beginning.

As stated in Section 4.3.1 it was revealed that 'Project Management and Procurement' was one of the least significant aspects affecting maintainability. All except 'evaluating the design scheme with life-cycle costing technique' were scored low. The benefits of Life-cycle costing have been recognized widely in both academia and the industry (Cunningham and Cox 1973; Bargh, 1987; Griffin, 1993; BRE, 2000). A few interviewees raised the concerns that without sufficient funds for maintenance, there were still many financial hurdles which must be overcome even though all other things were maintainable physically. They further added that this prototype of Maintainability Assessment Model might have insufficient consideration in maintenance costs. In this connection, it is worthwhile to point out that life-cycle costing is a good yardstick in evaluating the cost implication of decisions; however, it failed to assess other aspects such as safety. To depict a holistic picture of maintainability, it is advised that the life-cycle costing techniques and the prototype of this assessment model should be used collectively in assessing the maintainability of a building. This also created pleasing room for future refinement of this prototype and further research.

To come back to the subject, the reasons why 'using Design and Build (D&B) procurement System' and 'extraordinary longer defects liability period' do not have much significance on maintainability were investigated too. For another time, diverging views were expressed on these two issues. A few interviewees believed that neither contract arrangement nor better relationship between fragmented parties could help improving maintainability. It was the attitude towards maintainability and maintenance but not the contractual arrangement causing the problems. If longer DLP is stipulated in contract, extra risks posed will inevitably reflect in the contract sum, that is, higher costs to be incurred by the employer. Despite longer DLP, contracted parties may close up their business to escape from their liability since some of these firms are only subsidiaries as said above. All in all, the comments from the interviewees were generally in line with the findings in De Silva *et al.* (2004) who identified 8 key aspects in improving maintainability of buildings in Singapore where in their study 'greater use of D&B procurement system' and 'extended the defects liability period of structures/ buildings beyond the current 1 year' were ranked 7 and 8 respectively out of the 8 choices.

In the case of automation and maintainability, it was generally accept that certain automation and machinery were necessary to carrying out maintenance with ease, such as Building Management System (Figure 4.3) and aerial working platform, nevertheless, whether the application of machineries and automation systems do affect maintainability positively still depend on the actual situation. Usually decisions are made based on financial considerations and needs rather than maintainability. Works over escalators, for example, access can be provided only using metal working platform or scaffolding (bamboo/ metal) rather than hydraulic platform (Figure 4.4), whereas gondolas should be provided for high-rise office blocks where the demand for access to external envelope for maintenance purpose (e.g. cleaning, inspection, decoration, etc) is high. With regard to the financial position, it was thought that engaging manpower provided more flexibility than using machineries.

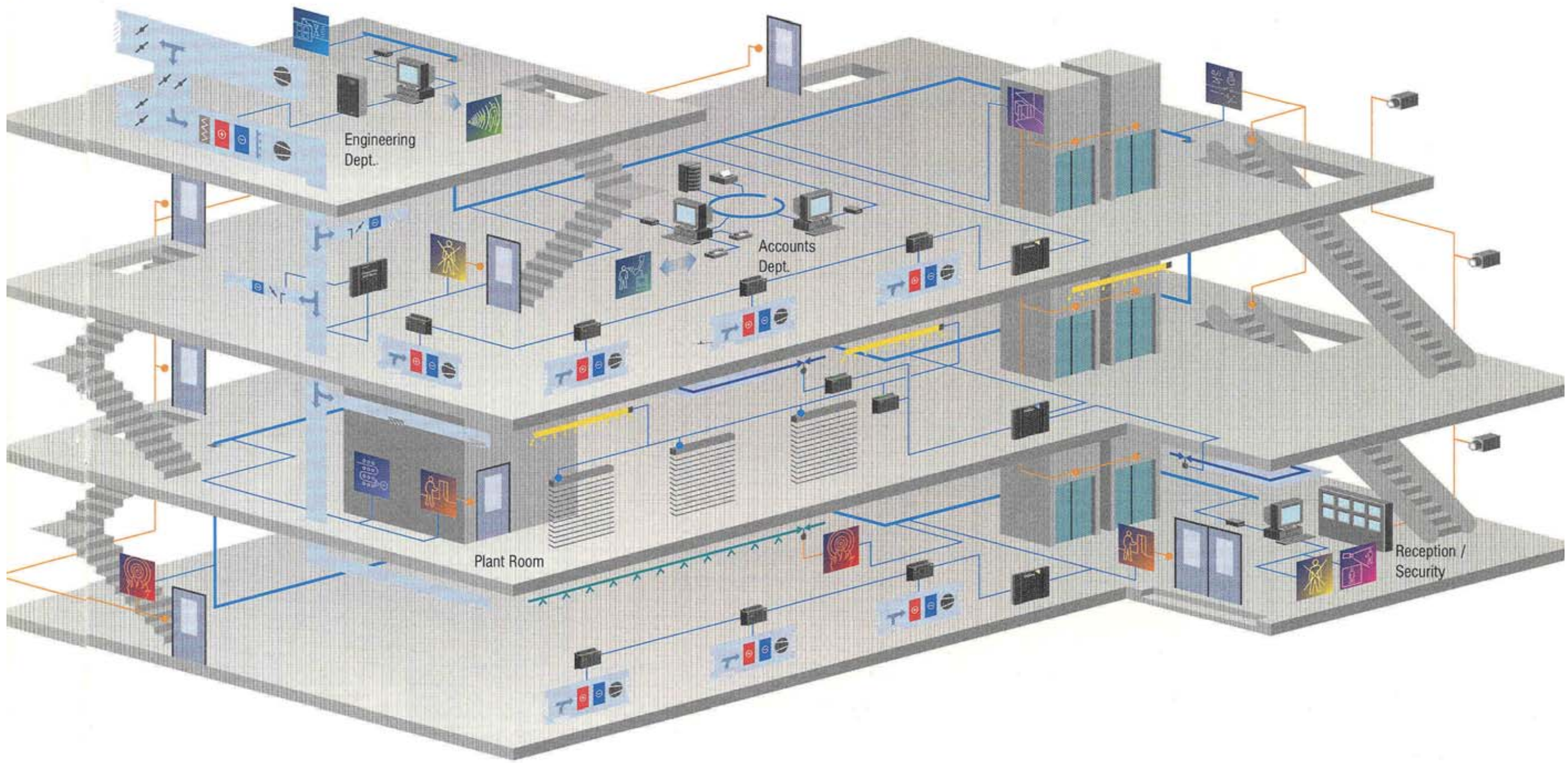


Figure 4.3 Illustration showing the concept of Building Management System and its installation in a building (source: Chan, 2007 adapted from ATAL Analogue Technical Agencies Ltd.)

Figure 4.4 Application of machineries to enhance maintainability depends on specific cases: mechanized platform cannot be used over escalator

Just about the end of this part, quite a number of the interviewees thought that unauthorized alteration did have significant maintainability implication. With clarification from the interviewer, no matter they violated the Buildings Ordinance or not, their presence was usually not acknowledged by the management authority, which imposed difficulties and extra efforts in maintenance. One example is the provision of pipe ducts in the 1980s to facilitate maintenance. From an interviewee’s experience, the occupiers usually alter the design and block the opening. As a result, an originally maintainable feature becomes useless and more problems arise from regaining access. Finally, the use of pipe ducts was abandoned and gave rise to later relocation of piping to external walls.

To end this section, the last point to add goes back to the very beginning, the structure of the project team. One thing revealed throughout the interviews were the different goals and objectives pursued by various involving parties. Developers, or clients, attempt to maximize their returns mainly in monetary terms, whilst architects, or building designers, pursue innovative and attractive designs within the allowed budget. As for property managers and maintenance managers, obviously, they aim at managing various aspects of buildings well to ensure the proper and smooth functioning of these parts. Due to this conflicting nature, compromises between parties should be reached to work out better solutions.

4.4.2 Construction Systems

As for construction systems, diverging views were aired for their implications on maintainability. Apart from the observations in clothing materials and their most suitable cleaning method, the types of plantation chosen in landscaping works (e.g. drought resisting plants require less watering) also points towards the suggestion that maintainability of construction system is inborn and inherited from the construction method or materials used. According to the opinions of some of the interviewees, however, this suggestion may not be applicable to construction systems.

Unlike other facilities in buildings such as building services systems which require periodic adjustment and maintenance, both service life and maintenance cycle of construction systems are comparatively much longer (Table 2.3, Table 4.13 and Figure 4.3). Only little attention is sufficient to maintain structural members in good state. Besides, possibly because of her colonial background, British Standards are followed in Hong Kong and the construction standards are high. Problems relating to structures are seldom especially in newer developments and further, most of the structural components are covered by finishes which protect them form weathering and mechanical or physical wearing. In this regard, a few interviewees expressed the idea that construction systems were irrelevant to maintainability on account of their scale in the whole process of maintenance. In addition, they held the view that neither the construction method nor the materials but the design layout affected maintainability. On the other hand, suggestions were put forward to narrow down the scope of assessment in construction system. Areas which require more frequent maintenance such as facades and roofing should be focused.

Having received these comments, it was interpreted that construction systems might have little or even no implication on maintainability. Thus, another prototype of the assessment model without this part system is proposed in chapter 5.

Shearing Layers	Description	Typical Lifespan
Site	Location and context	Permanent
Structure	Bones (i.e. structures, construction system)	30 – 300 years
Skin	Envelope (i.e. finishing systems)	20 years +
Services	Lifeblood (i.e. building services systems)	7 – 20 years
Space plan	Interior layout (i.e. fittings and decorations)	3 years
Stuff	Furniture and equipment	Under 3 years

Table 4.13 The 6 shearing layers of change and their typical lifespan (source Brand, 1993; Douglas, 1996)

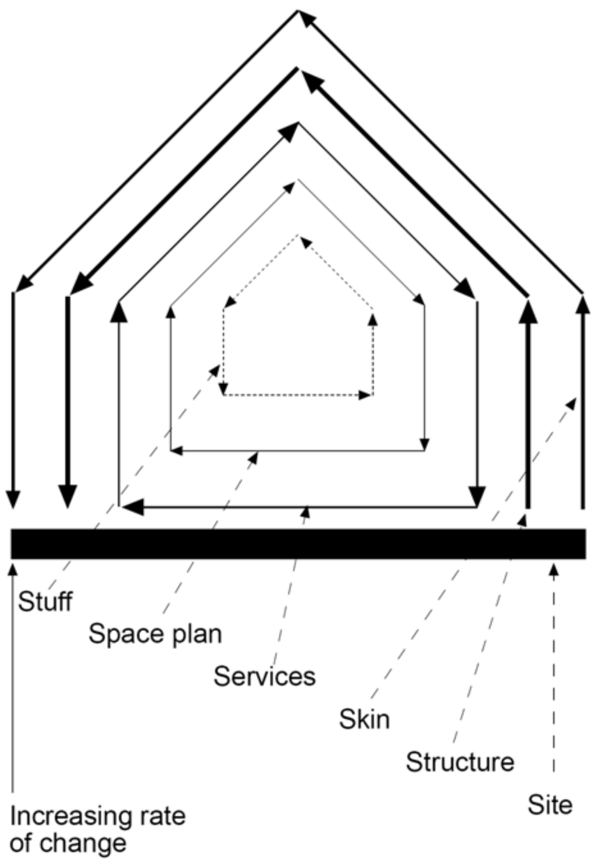


Figure 4.5 Interrelationship between the 6 shearing layers and their rate of change (source Brand, 1993; Douglas, 1996)

4.4.3 Finishing Systems

As reported in Section 4.3.3, the interviewees generally agreed that different finishing systems were unlike in terms of maintainability. This characteristic ultimately determines the efforts required in maintenance. Covering the structural members, finishing systems are exposed directly to external environment. More frequent maintenance is required as a result of physical and mechanical wearing, accumulation of dirt and deterioration resulting from weathering effects.

Regarding the maintainability of different finishing systems, some interviewees pointed out that even the same finish may exhibit different traits in cleaning, repairing and replacing. Marble and granite, for example, can be cleaned and removed easily; yet, from another perspective it is almost impossible to find a replacement that matches the original pattern perfectly when a piece is smashed. Carpet, on the other hand, is often applied in acoustic environment even though with its low maintainability as shown in the survey result.

For this reason, two important messages were conveyed by the interviewees. First, user requirement and functional requirement are fulfilled above all in choosing design schemes and materials. Almost at no time maintenance consideration is at the top of the project team, or the maintenance problems are simply overcome by choosing more durable materials. In hotel lobbies, one will not use ceramic tiles as the wall finishes. Second, the issue of management and maintenance policy is addressed. Depending on the building type, expectation over management and maintenance can entirely be different. For instance, it is expected that better quality management and maintenance should be provided in more prestigious housings and Grade A offices, on the contrary, owners from low-end housings may want a solution that incurs lowest cost with substandard works as tradeoff. Consequently, more efforts are still needed to maintain the former building type even though same material is used. From another point of view, this possibly explained why maintainability has been overlooked for years (Figure 4.4). Taking shopping mall as an example where the life-cycle of fittings is short to keep the shopping experience fresh, less attention is paid on maintainability in those areas which renovate frequently. The economic life-cycle of these works ends much earlier than their physical life that they are removed before starting to deteriorate.

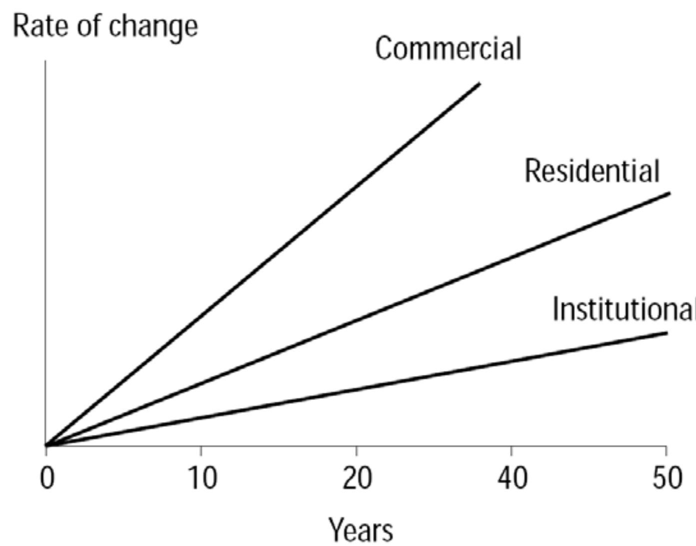


Figure 4.6 Rate of change in different buildings: because of different function, nature and objectives to be achieved by buildings, different rate of change is observed (source: Douglas, 1996)

4.4.4 Aspects in Building Services Systems and Site/ Locational Factors

Concerning the maintainability of building in building services systems aspect, most interviewees believed that the features in the survey question do have positive implications onto the subject. A utopia in maintenance can be created if most of the aforementioned features are incorporated in building services systems.

In real world, the designs are usually in the other way, for example, inadequate access to plant room and absence of coordination of parts in a system. It is not uncommon that plant rooms are located in areas which are unfavourable to maintenance and small in size, e.g. on second floor or in the basement without adequate access and sufficient space. Indeed, as a business decision it was agreed that there was nothing improper to relocate plant rooms to places with less commercial value and maximize the Gross Floor Sale (GFA) or the Saleable Floor Area (SFA). In this regard, some believed that reasonable steps should be taken to rectify these limitations in design and they were the responsibility and expertise of property managers and maintenance managers, who are specialist in maintenance, to work out solutions rather than facilitating maintenance by modifying the design – assigning plant rooms to prime locations at the expenses of huge business interests. Whilst others did not agree on this and held the view that both the developers and the architects should give more consideration in maintenance right from planning and design stage. Regardless of these approaches, equilibrium should be established between commercial benefits and ease of maintenance, in particular, in buildings for the purpose of investment and long-term occupancy.

Coordination within or between systems is equally important in enhancing maintainability. Although maintainable features are sometimes incorporated in systems, without coordination it would be complete waste of money and efforts. An example suggested by an interviewee was the drainage installation in a luxury housing development. In spite of the provision of cleaning eye which provides access for cleaning inside the drain pipes, without coordination space allowed for cleaning was insufficient which rendered the maintainable feature, the cleaning eye, useless rather than as 'decoration' in this case.

For the site/ locational factors, it was thought that their impact on maintainability was insignificant and they are just the icing on the cake. Whether they are actually advantageous to maintenance still depend on a particular situation. Concerns about safety and access once again dominate the result.

4.5 Summary

Findings from structured interviews with 13 experienced property managers and maintenance managers have been report in this chapter. They comprise quantitative and qualitative information whereas the former is arranged and presented in 6 parts. It provides essential information in numerical forms for developing the assessment model, that is, the relative importance indices and maintainability weightings amongst components. Rankings are worked out as well as a side product in a way that the relative contribution and significant of practices, built form, etc, towards maintainability of building can be examined. Useful information on the subject of building maintenance and maintainability of buildings in Hong Kong are also collected and reported. With all these information as the foundation stone, the Maintainability Assessment Model is developed and its assessment mechanism is explained in the next chapter.

CHAPTER 5 DEVELOPMENT OF THE MAINTAINABILITY ASSESSMENT MODEL AND ITS ASSESSMENT MECHANISM

5.1 Introduction

In this chapter, the principles of the Maintainability Assessment Model are introduced followed by brief explanations to its assessment mechanism. Using the findings of the structured interviews reported in Chapter 4, two essential elements in the model namely the Maintainability Weightings and the Relative Importance Indices (i.e. Maintainability Index of individual item) are established. The Maintainability Weightings represent the relative contribution towards the overall building maintainability among components in numerical terms whilst the Relative Importance Indices (also Maintainability Indices) indicate the relative maintainability of items of certain component in the assessment model. At length, the Maintainability Assessment Model is developed and explained.

5.2 Principle of the Maintainability Assessment Model

The principle and the making of the Maintainability Assessment Model are discussed thereinafter. To start with, the overall maintainability index of a building in a given time is represented mathematically as:

$$M_I = f\,(M_{IM}, M_{IS}, M_{IL}, M_{IE}, M_{IF}, M_{IB}, M_{IP}, M_{IO})$$

Where M_I is the overall building maintainability index and M_{IM}, M_{IS}, M_{IL}, M_{IE}, M_{IF}, M_{IB}, M_{IP} are maintainability index of pre and post-occupancy practices or features, structural frame, slab, building envelope, finishes, building services system, locational/ site factors respectively contributing to maintainability accordingly. M_{IO} is the provided for open-ended maintainable features which are not included in the assessment mechanism. The respective maintainability index of components is given below:

Pre and post-occupancy maintainable practices:

$$M_{IM} = 23\ \Sigma\ (\text{cov}_{mp} \text{ x } M_{IMP}) \text{ / Sum of all applicable } M_{IMP} \quad \cdots\cdots (1)$$

Construction System (Structural Frame)

$$M_{IS} = 6\ \Sigma(\text{V}_\text{S} \text{ x } M_{ISF}) \quad \cdots\cdots (2)$$

Construction System (Slabs/ Roofs)

$$M_{IL} = 5\ \Sigma(\text{A}_\text{L} \text{ x } M_{ISL}) \quad \cdots\cdots (3)$$

Construction System (Building Envelope)

$$M_{IE} = 12\ \Sigma(\text{A}_\text{E} \text{ x } M_{ISE}) \quad \cdots\cdots (4)$$

Maintainability of Building Services System

$$M_{IB} = 26\ \Sigma(\text{cov}_{bs} \text{ x } M_{IBS}) \text{/ Sum of all } M_{IBS}) \quad \cdots\cdots (5)$$

Site/ Locational Factors

$$M_{IP} = 7\ \Sigma\ M_{ISS} \text{/ Sum of all applicable } M_{ISS} \quad \cdots\cdots (6)$$

For M_{IF}, i.e. Maintainability Index of Finishing System, it is computed using the following equation:

Finishing System

$$M_{IF} = 20\ \Sigma(\text{A}_{IC} \text{ x } M_{IIC}) + 20\ \Sigma(\text{A}_{IW} \text{ x } M_{IIW}) + 18\ \Sigma(\text{A}_{IF} \text{ x } M_{IIF}) + 26\ \Sigma(\text{A}_{EW} \text{ x } M_{IEW}) +$$

Finishing systems for Internal Ceilings	Finishing systems for Internal Walls	Finishing systems for Internal Floors	Finishing systems for External Walls

$$16\ \Sigma(\text{A}_{RF} \text{ x } M_{IRF}) \quad \cdots\cdots (7)$$

Finishing systems for Roofing

In short, the equation to compute the overall maintainability index, M_I, is:

M_I = 23 Σ M_{IMP} / Sum of all applicable M_{IMP} + 6 Σ(V_S x M_{ISF}) + 5 Σ(A_L x M_{ISL}) +

| Pre and post-occupancy maintainable practices | Structural Frame | Slabs and Roofs |

12 Σ(A_E x M_{ISE}) +10 (M_{IF} /100) + 26 Σ(cov_{bs} x M_{IBS})/ Sum of all M_{IBS}) +

| Building Envelope | Finishing Systems | Building Services Systems |

7 Σ M_{ISS}/ Sum of all applicable M_{ISS} + M_{IO} (Maximum bonus points of 10)

| Site/ Locational Factors | Others |

In response to the comments received from the interviewees, alternatively, the model without assessing the construction system is:

M_I = 30 Σ M_{IMP} / Sum of all applicable M_{IMP} + 14 (M_{IF} /100) +

| Pre and post-occupancy maintainable practices | Finishing Systems |

35 Σ(cov_{bs} x M_{IBS})/ Sum of all M_{IBS}) +9 Σ M_{ISS}/ Sum of all applicable M_{ISS} +

| Building Services Systems | Site/ Locational Factors |

M_{IO} (Maximum bonus points of 12)

| Others |

Where

M_{IM} = Maintainability index of pre and post-occupancy maintainable practices

M_{IS} = Maintainability index of structural frame

M_{IL} = Maintainability index of slabs and roofs

M_{IE} = Maintainability index of building envelope

M_{IF} = Maintainability index of finishing systems

M_{IB} = Maintainability index of building services systems

M_{IP} = Maintainability index of site/ locational factors

M_{IO} = Bonus points provided for other maintainable features

V_S = Percentage of total volume of structural frame using a particular structural form

i.e. (Volume of structural frame using a particular structural form/ Total volume of structural frame) x 100%

A_L = Percentage of total construction floor area using a particular slab form
i.e. (Construction floor area using a particular slab form/ Total slab areas including roof) x 100%
A_E = Percentage of total elevation area using a particular form of building envelope
i.e. (Elevation area using a particular form of building envelope/ Total areas of building envelope) x 100%
A_{IC} = Percentage of total construction area at internal ceilings applying a particular finishing system
i.e. (Construction area at internal ceilings applying a particular finishing system / Total areas of internal ceiling) x 100%
A_{IW} = Percentage of total elevation area at internal walls applying a particular finishing system
i.e. (Elevation area at internal walls applying a particular finishing system / Total areas of internal walls) x 100%
A_{IF} = Percentage of total construction floor area at internal floors applying a particular finishing system
i.e. (Construction floor area at internal floors applying a particular finishing system / Total areas of internal floors) x 100%
A_{EW} = Percentage of total elevation area at external walls applying a particular finishing system
i.e. (Elevation area at external walls applying a particular finishing system / Total areas of external walls) x 100%
A_{RF} = Percentage of total construction floor area applying a particular finishing system at roofing
i.e. (Construction floor area at internal floors applying a particular finishing system / Total areas of roofing) x 100%

M_{IMP} = Maintainability index for a particular pre or post-occupancy maintainable practice
M_{ISF} = Maintainability index for a particular structural form
M_{ISL} = Maintainability index for a particular slab form
M_{ISE} = Maintainability index for a particular form of building envelope
M_{IBS} = Maintainability index for a particular criterion in building services system
M_{ISS} = Maintainability index for a particular locational/ site factor

M_{IIC} = Maintainability index for a particular finishing system at internal ceilings
M_{IIW} = Maintainability index for a particular finishing system at internal walls
M_{IIF} = Maintainability index for a particular finishing system at internal floors
M_{IEW} = Maintainability index for a particular finishing system at external walls
M_{IRF} = Maintainability index for a particular finishing system at roofing
cov_{BS} = Percentage coverage of a particular feature in building services system

On the whole, to work out the overall maintainability of a building 7 aspects are assessed. They include Structural Frame Systems, Slab Systems, Building Envelope Systems, Finishing Systems and Building Services Systems for the design consideration and choice of materials from maintainability perspective, as well as the Locational/ Site Factors and the Pre and Post-occupancy Maintainable Practices.

Having completed the assessment in the above 7 aspects, the respective Maintainability Index could be calculated and added up to give the overall Maintainability Index of a building, M_I. Simply speaking, the Maintainability Indices of the Structural Frame Systems, Slab Systems, Building Envelope Systems and Finishing Systems are computed using the proportionate volume or area coverage and corresponding Relative Importance Indices. In like manner, Building Services Systems, Site/ Locational Factors and Pre and Post-Occupancy Maintainable Practices are assessed against lists of subjects related to maintainability. An open statement component, M_{IO}, is provided for innovative methods contributing to good maintainability that are not included in the assessment model.

5.3 Findings from Structured Interviews

As mentioned earlier, the Maintainability Weightings and the Relative Importance Indices are established on the basis of the findings from the structured interviews. The shaded numbers in the equation for calculating the overall building maintainability index above (i.e. equation 1 to 6) are the Maintainability Weightings amongst 6 components in a building from maintainability perspective together with the Finishing Systems in which finishes applied at different locations are assigned weightings by the interviewee. These Maintainability Weightings are tabulated and reported in Table 4.8 and Table 4.11 respectively.

5.4 Assessment of the Construction Systems

On account of the fact that different designs and choices of materials are subject to different maintainability, construction systems of a building are assessed. In this scheme, the three construction systems, Structural Frame Systems, Slab/ Roof Systems and Building Envelope Systems are assessed separately. The corresponding Maintainability Index for a particular design form is derived from the structured interviews and showed in Table 4.6. In assessing the Structural Frame Systems, the total Maintainability Index of this part, M_{IS}, is the summation of the products of the respective proportionate volume of structural components using a particular structural form in percentage (i.e. volume of structural frame using a particular structural form/ Total volume of structural frame x 100%) and the Maintainability Index of that particular structural system, M_{ISF}, that is,

$$M_{IS} \quad = 6\ \Sigma(V_S \times M_{ISF})$$

In a similar way, the total Maintainability Index of the Slab/ Roof Systems, M_{IL}, is the summation of the products of the respective proportionate construction floor area using a particular slab form in percentage and the Maintainability Index of that particular slab form, M_{ISL}, that is,

$$M_{IL} = 5\ \Sigma(A_L \times M_{ISL})$$

Furthermore, the total Maintainability Index of the Building Envelope, M_{IE}, is the sum of the products of the respective proportionate elevation area using a particular form of envelope in percentage and the Maintainability Index of that particular form, M_{ISE}, that is,

$$M_{IE} = 12\ \Sigma(A_E \times M_{ISE})$$

Without standard rules of measurement discrepancies are anticipated in measuring the proportionate volumes and areas. For that reason, rules set out in the Standard Method of Measurement of Building Works (SMM7) (RICS, 1998) are adopted and served as guidelines in any event. Under normal circumstances, only a few additional measurements are required with the bills of quantities. On the contrary, approximate measurements are sufficient for the purpose of assessment without the bills of quantities or other necessary data on hand.

5.5 Assessment of the Finishing Systems

Finishes applied at different locations will inevitably have different performance in terms of maintainability. Even though in the same location efforts are made differently to maintain finishes of different type. Thus, the assessment of the finishing systems is divided into 5 parts according to the respective locations: Internal Ceilings, Internal Walls, Internal Floors, External Walls and Roofing. Utilizing the findings from the structured interviews, weightings are assigned among these parts which are shown in Table 4.8 and the Maintainability Index of the Finishing Systems, M_{IF}, is calculated using the following equation:

$$M_{IF} = 20\ \Sigma(A_{IC} \times M_{IIC}) + 20\ \Sigma(A_{IW} \times M_{IIW}) + 18\ \Sigma(A_{IF} \times M_{IIF}) + 26\ \Sigma(A_{EW} \times M_{IEW}) + 16\ \Sigma(A_{RF} \times M_{IRF})$$

Similarly, the overall Maintainability Index of individual finishing systems is the sum of the products of the respective proportionate area applying a particular finish type in percentage and the Maintainability Index of that finishing system (e.g. M_{IIC}, M_{IIW}, etc). The overall Maintainability Index of Finishing Systems, M_{IF}, is the sum of the aforesaid Maintainability Indices of individual finishing systems at different location. For the Maintainability Indices of finishing systems applied at different locations, they are shown in Table 4.7.

5.6 Assessment of Pre and Post-occupancy Maintainable Practices

In assessing the maintainability of pre and post-occupancy maintainable practices or features, its Maintainability Index, M_{IM}, is the summation of the products of the respective proportion (default = 25%, 50%, 75% and 100%) of a particular practice and the Maintainability index of that particular practice, M_{IMP}, divided by the total Maintainability Index of all practices under this category:

$$M_{IM} = 23\ \Sigma\ (\mathrm{cov}_{mp} \times M_{IMP}) \ / \ \text{Sum of all applicable } M_{IMP}$$

Since some of the practices cannot be evaluated in proportion, e.g. either yes or no, in this case, 100% is taken and the following equation prevails as:

$$\text{Maintainability Index of a particular practice} = M_{IMP} \ / \ \text{Sum of all applicable } M_{IMP}$$

The detailed Maintainability Index of a particular pre and post-occupancy practice can refer to Table 4.4 and Table 4.5.

5.7 Assessment of Building Services Systems

Regarding the assessment of Building Services System in the Maintainability Assessment Model, the Maintainability Index, M_{IB}, is the summation of the products of the respective proportion (default = 25%, 50%, 75% and 100%) of a particular criterion in building services aspect and the Maintainability Index of that criterion in building services system, in addition, divided by the total Maintainability Index of all criteria in the building services systems, that is

$$M_{IB} = 26\ \Sigma(\mathrm{cov}_{bs} \times M_{IBS}) / \text{Sum of all } M_{IBS})$$

The Maintainability Indices of particular criteria in the building services systems are shown in Table 4.9, again, these values are derived from the findings of the structured interviews.

5.8 Assessment of Locational/ Site Factors

The total Maintainability of Locational/ Site Factors, M_{IP}, is calculated by dividing the sum of those qualified Locational/ Site Factors, M_{ISS}, by the total Maintainability Indices of all applicable Locational/ Site Factors, that is

$$M_{IP} = 7\ \Sigma\ M_{ISS} / \text{Sum of all applicable } M_{ISS}$$

When a holistic picture is considered, it is believed that maintainability will be affected by surrounding environments to the location where the maintenance tasks are executed. The Maintainability Indices of the Locational/ Site Factors, M_{ISS}, are displayed in table 4.10.

5.9 'Others' Provided for Innovations in Maintenance

Advances in technology and new approaches to maintenance management which can facilitate maintenance tasks may not be covered by this assessment scheme and expected to appear in the near future. In this regard, a maximum of 10 points are provided for any innovations and new measures which are proved to be capable of enhancing the maintainability of buildings.

5.10 Application of Information Technology in the Assessment Process

The assessment of maintainability of building can be carried out either manually or electronically. An Assessment Proforma (please see Appendix N) is developed for collecting the data that are necessary for assessment. Manual assessment requires filing up of data in the hard copy version of the proforma for subsequent calculation, however, this method is less reliable and time consuming. Thanks to the rapid evolution in Information Technology, the assessment can be conducted electronically utilizing electronic spreadsheet application such as Microsoft Excel. Moreover, measurement of building elements can be minimized provided that the quantities (e.g. volumes of structural system, area of internal floor finishes, etc) are readily available in the Bills of Quantities of new construction as well as repair works.

5.11 Summary

The principle and the assessment mechanism of the Maintainability Assessment Model have been discussed in depth in this chapter. Due explanation has been made to each assessment aspect and its way of computation. Generally speaking, the assessment is divided into 7 parts including construction systems used, maintainable practices in pre and post-occupancy stage, design characteristics of building services system and locational/ site factors. Moreover, bonus points are provided for other maintainable features or innovations which have not been covered.

In the absence of sufficient time and resources, the model cannot be validated in this stage. This leaves a pleasing room to validate and fine tune the model in the future. In the following chapter, conclusion of this dissertation will be given.

CHAPTER 6 CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

Serving as the conclusion of this study, this chapter summarizes the contributions made in previous chapters. Therefore, the key findings and outcomes are summarized and reported. In the meantime, the stated objectives are reiterated and reviewed. Following this the limitations of the study are given and areas for future research are proposed eventually.

6.2 Summary of Contributions

In the era of growing complexity in buildings, immediate attention to ease of maintenance should be given or else the problem of the enormous cost of their upkeep is going to become more serious than any time in history. In academia, researchers have been more aware of the opportunities in maintainability in saving maintenance costs and meantime achieving better functioning of facilities. Furthermore, safety in maintenance is of paramount importance in achieving good results. In any event, it should not play second fiddle to financial and economical considerations (Figure 2.5). These grounds provided a basis that call for ease of maintenance, or in other words, more maintainable buildings are demanded.

Distinct from various disciplines in engineering such as software engineering, studies on building maintainability are very limited. In practice, the importance of building maintainability was not realized until the Construction 21 Steering Committee (CTC) commissioned by the Ministry of Manpower (MOM) and the Ministry of National Development in Singapore identified maintainability as one of the major areas to be achieved to improve the performance of the Singaporean construction industry. Whilst in Hong Kong, improving the maintainability of buildings is necessary too on account of the ageing trend of building stocks, the proposed Mandatory Building Inspection Scheme

(MBIS) as well as the costs incurred in maintenance. In this regard, the author was inspired to initiate this research so as to develop an assessment model to quantify the abstract notion of maintainability which enables involving parties throughout the whole life cycle of buildings to evaluate and check the impact of their decisions on building maintainability accurately and objectively. As a result, it is hoped that the overall building maintainability in the local built environment can be improved gradually.

Maintainability of building as a whole focuses on ease and effectiveness of maintenance. Optimal maintenance processes can be achieved through incorporating the concept of maintainability in planning, designing and managing facilities. In principle, in maintaining a building with high maintainability, less effort is required but still the same or even better outcome is resulted. On that account, maintainability of building at a given time may be regarded as the extent building facilities allow for maintenance. It can be expressed in terms of the resources required and the performance of maintenance.

To fulfill the aim to develop an assessment model for assessing maintainability of buildings, 5 objectives are decided. In the absence of knowledge in maintainability, the model can hardly be developed. Thus, factors and elements in design, planning and management aspects affecting building maintainability are identified in the first instance. The research process and the assessment framework are then designed and constructed accordingly. Because of the time constraints in this research, structured interviewees are arranged to find out the relative importance and weightings of the factors and elements in respect of maintainability. Resting on these findings, guides to improve building maintainability are produced and the prototype of the assessment model can be developed.

In the course of conducting the research, the idea of building maintenance is well defined before progressing. A few type of maintenance is introduced and the needs to provide maintenance which cannot be eliminated are stressed subsequently in physical, economic and legal aspects. Selected issues relating to building maintenance in Hong Kong are then discussed. They include the economic scale of local building maintenance activities, problems and defects that are commonly found in local buildings, the laws regulating maintenance and the proposed MBIS.

Regarding building maintainability, this concept is explored first to establish the theoretical framework. Afterwards, the reason which this concept is proposed is due to the soaring cost in maintenance. Subsequently, factors that attributable to maintainability of buildings are reviewed. Provision of adequate access is often top ranked in the subject of maintainability, nonetheless, personnel's awareness and knowledge and availability of necessary maintenance facilities are important too. Design is always regarded as the most critical factor affecting maintainability in the past. On the contrary, it is thought that proper management of the building after completion plays similar role in enhancing maintainability.

As mentioned earlier, the primary objective of the structured interviews are arranged to find out the relative importance and weightings of the factors and elements in respect of maintainability. In this regard, the interview comprise of a quantitative and a qualitative module. For the quantitative module, surveys on 6 aspects in a building relating to maintainability are conducted to establish the Maintainability indices of individual items and decide the weightings which represent the relative importance amongst components in the assessment model, whilst for the qualitative module, the interviewees' experience in maintenance is injected to refine the constructed assessment framework and probe into various maintenance issues in Hong Kong. At this stage, the target interviewees are confined to property managers and facility managers only who are directly involving in maintenance tasks.

The collected data from the interviews are then analyzed and discussed. In analyzing the collected data, the Relative Importance Indices method put forward by Tam *et al.* (2000) was adopted. As implied in the name, the Relative Importance Index of an individual item can be computed using this method base on the data collected from 13 structured interviews with very experience property managers and maintenance managers who hold key positions in the building industry. In the meantime, items can be ranked according to the magnitude of their respective index. Therefore, more significant features or measures are sorted out.

Regarding the pre and post-occupancy features or measures contributing to maintainability, providing adequate access, enabling safe maintenance and awareness in maintainability by the involving parties are identified as the most significant areas in enhancing maintainability of building. For the construction systems, diverging views were aired and the message that construction systems had little or even no significance in maintainability was conveyed during the interviews. In response to this two prototypes of the Maintainability Assessment Model are proposed (please refer Section 5.2 in Chapter 5), the only difference between them is that the component to assess the maintainability of construction systems is removed in one of the prototypes. In the case of finishing systems, most interviewees agreed that the overall building maintainability is subject to the finishes applied. The underlying reason is that these finishes are exposed to the external environment directly, or in other words, they require comparatively much more frequent maintenance for they are directly subject to mechanical wearing and climatic conditions. Metal suspended ceiling, wall tiles, marble or granite slabs, glass and tiles on bitumen felt built-up roofing were top ranked finishing system in their respective applied location. They are characterized by enabling easy cleaning, repair, fixing and replacing.

The maintainability of building services systems is another area that contributes to the overall maintainability of building significantly. In light of the relatively shorter maintenance cycle, these systems require periodical adjustment and servicing to avoid system breakdown. Enabling ease of disassembly and assembly, locating systems with adequate access and space and managing documentation and details of these systems well are the three most importance attributes affecting the maintainability of building services systems. For the site/ locational factors, it was thought that their impact on maintainability was insignificant. Concerns about safety and access once again dominate the result as the safety concerns for underground maintenance and providing adequate access are top rated.

To add knowledge in the area of maintainability of building, attempts have been made to find out the reason behind the choices made by the interviewees. Investment properties are considered to have better performance in maintainability compare with properties developed for sale. Involvement of maintenance managers during detailed design stage is general perceived as necessary for enhancing building maintainability. Another point to highlight is that awareness in constructing maintainable buildings by the involving personnel is crucial in enhancing the maintainability of our built environment than any other measures such as shifting to the use of Design and Build (D&B) procurement system and longer Defects Liability Period (DLP). For the construction systems, because of their long life and maintenance cycle, their roles in the overall maintainability of building are less important. Nevertheless, the maintenance problems occur in the construction systems should not be overlooked, especially for buildings under humid conditions like Hong Kong where building structures deteriorate at a much higher rate. To fine tune the assessment mechanism, certain areas like the building façade and roofing in which require more maintenance should be focused in the future refinement.

In summary, this research has developed an assessment framework to evaluate the maintainability of buildings. With this model parties involving in building development and management are able to check the implication of their decisions on maintainability objectively and accurately. Through this research, it is hoped that maintainable features and measures identified can be utilized and incorporated in planning, designing and managing buildings. Investors or building occupiers can be clearer about their financial positions in owning properties as maintainability of building is an indirect indicator of maintenance costs required. In the long-run, it is hoped that this research can contribute to the society as a whole by improving the built environment gradually.

6.3 Review of Research Objectives

As stated in Chapter 1, the core of this study was to develop an assessment model to quantify the abstract notion of maintainability for appraising the maintainability of buildings from planning, design and managerial aspects. This model, together with the findings which exert positive influence on ease of maintenance, can essentially be engaged to enhance the maintainability of buildings in Hong Kong. The following objectives have been successfully achieved in the respective Chapters specified below:

- To identify factors and elements in design, planning and management aspects that affect the maintainability of building (Chapter 2 and Chapter 3);

- To construct a framework for assessing the maintainability of building (Chapter 5);

- To find out the relative importance and weightings of the aforesaid factors and elements in respect of maintainability through structured interviews (Chapter 4);

- Founding on 1) and 3), to devise stratagems from the identified essentials to improve building maintainability (Chapter 4); and

- With 1) to 3) as underpinnings, to develop an assessment model with detailed explanation to its assessment mechanism (Chapter 5)

6.4 Limitation of the Study

In view of the idea that academic research should go for perfection, there are always deep regrets due to the limited time and resources available for this study. To begin with, the validity and reliability of the result heavily depends on the sample size. Regardless of the high profile of the interviewees who are all very experienced practitioners and hold key positions in the industry, on account of the number of practitioners in property management and maintenance management, definitely, a more realistic and objective picture can be depicted if the number of interviews increases. Moreover, property managers and maintenance managers are only one group of the professionals involving in the whole life cycle of buildings. Further views from other involving parties like developers, architects, engineers, etc, should be sought to fine-tune the model. After all, despite the small sample size and views from a single, specific group, this study still qualifies as a start to probe into realm of maintainability and serving as a pilot study.

The second limitation is the insufficient consideration in the dimension of costs. In Section 4.4.1 this problem has been highlighted. For that reason the explanatory power of this prototype of Maintainability Assessment Model is limited to physical and managerial elements affecting maintainability. Where costs in maintaining buildings or facilities are concerned, the life-cycle costing technique should be used collectively with the model at this stage to conduct an all-round evaluation in maintainability.

The third limitation is the generality of this prototype of the assessment model. Problems may turn up for the variances in maintenance objectives in different types of buildings. This issue has been come across in Section 4.4.3. Under the circumstances that two different sets of maintenance objectives exist in two physically identical buildings, still efforts have to make differently to maintain them. Deviation may be resulted and the question of objectivity may be raised in assessing buildings of different types using the same assessment mechanism.

When the actual assessment procedures are taken into account, very often the assessment will be confined to common areas and external environments in occupied buildings. Without full cooperation from the occupiers, the assessment can only rely on the information collected from the aforesaid areas. The implication of this limitation should not be underestimated because for many times problems in maintenance occur in these exclusively occupied areas.

Last but not least, because of the time constraints neither test nor validation has been carried out to examine the practicability or verify the efficacy of the model.

Notwithstanding the absence of validation, the study can contribute through putting forward key aspects which are favourable to good maintainability.

6.5 Further Areas of the Study

On the whole, the Maintainability Assessment Model developed at this stage is just a prototype in which subsequent refinements are required, but then it has initiated the framework for assessing maintainability of buildings and new research areas are opened up thereafter. In this regard, for the model itself a greater sample size is required to enhance its persuasiveness and accuracy, that is, more injection of experiences from relevant practitioners. Moreover, participation of all involving parties in the building industry is necessary whereas at present participation is confined to property managers and maintenance managers only. A conclusive assessment model can possibly be developed through subsequent validation of the assessment model using representative building cases with the addition of the aforesaid follow-ups.

On the other hand, the assessment mechanisms are subject to improvements. To resolve the problems associated with the variances in maintenance objectives in different building types, further development of the model should go in a way from general to particular – narrowing down the scope of the assessment model into certain types of building, for instance, to construct models for assessing the maintainability of residential buildings and office buildings separately, with corresponding revisions to these models. Besides developing the model according to the building type, alternatively, the model may be developed to assess the maintainability of certain building elements which require frequent maintenance, such as façade (Chew *et al.*, 2004), roofing and building services systems. Furthermore, more elements in cost should be incorporated. Indeed, to implement maintenance programme successfully financial considerations cannot be ignored. Taking cost elements into account can balance between maintainability and costs incurred such that the latter will be not extraordinarily high.

Apart from further refining the assessment model, the maintainability of construction materials is expected to attract great interests for further research. In this study, it is learnt that certain building elements like finishing systems exhibit different characteristics in maintainability. At the same time achieving a hundred percent reliability is almost unobtainable goal at a reasonable cost in reality (Blanchard, 1969), all building elements will inevitably and eventually require maintenance. Hence, instead of researching the durability of materials, the maintainability of materials is equally important. Optimal solutions regarding user and functional requirement as well as the life-cycle costing can be delivered with this information.

To end, attentive services are usually not necessary to building occupiers, for example, one will not expect the management to carry out daily inspection of the external envelope to ensure its structural soundness. At a given maintenance budget, one may pursue cost effectiveness rather absolute perfection in the property under management. Evaluating the cost effectiveness of property management objectively and the dimensions for such evaluation are therefore worth further research.

6.6 Concluding Remarks

Driven by the ambition to create a more sustainable built environment through enhancing the maintainability of buildings, attempts have been made to explore the area of building maintainability. The eventual outcomes are the prototype of Maintainability Assessment Model and series of discoveries in local building industry relating to maintainability. The dissertation has achieved its intended objectives as mentioned in Chapter 1.

In the near future, it is desirous to see more research and discussion in both the industry and the academia to get the built environment to a more maintainable one to benefit the society as a whole. Corrections and feedback on the work are always welcome.

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APPENDIX A

SAMPLE OF SURVEY QUESTIONS

PRE AND POST-OCCUPANCY PRACTICES/ FEATURES AFFECTING MAINTAINABILITY

Interview for Developing the Building Maintainability Index

More maintainable buildings and enhanced building maintainability have been demanded worldwide for the sake of saving costs in maintenance, knocking down difficulties in maintenance resulting from more complex building design and more frequent occurrences of defects, improving the quality of life for the community and the environmental performance, etc. In local context, for instance, the Construction Review Industry Review Committee (CIRC) Reports proposed measures to promote more maintainable buildings.

In the absence of a measure of building maintainability, we can hardly talk about improving building maintainability in Hong Kong.

Objective of this interview: To establish a proper measure of building maintainability, this survey aims to identify the attributes and the designs affecting building maintainability in the Hong Kong.

Your support to this research is highly appreciated!

In this interview, Building Maintainability refers to ease of maintenance, i.e. the condition of an item or a surface that permits its repair, adjustment, or cleaning with reasonable effort and cost (Feldman, 1975)

PART I: Survey on Pre and Post-occupancy Practices/ Features Affecting Maintainability

Please answer the questions by circling the appropriate number where:

5=**Very high importance or impact on the maintainability** of building in a particular context.
4
3 } Intermediate level between 5 and 1
2
1= **Very low importance or impact on the maintainability** of building in a particular context.

Please cross all the five numbers when the issue is not applicable to maintainability.

No.	**Practices or Features** (Please give your opinion in the context of the Hong Kong construction industry.)	**Importance** High← →Low				
	Examples					
	An example indicating 'very high importance to maintainability'	(5)	4	3	2	1
	An example indicating that 'it is not applicable to maintainability'	~~5~~	~~4~~	~~3~~	~~2~~	~~1~~
Part A: Practices or Features Contributing to Maintainability in Pre Occupancy Stages						
1.0	**Involvement of Property Manager or Maintenance Manager**					
1.1	Participation of experienced maintenance manager during the design process	5	4	3	2	1
1.2	Future maintenance manger involves in the supervision of construction works to facilitate future maintenance tasks	5	4	3	2	1
	Others, please specify:					
2.0	**Project Management and Procurement**					
2.1	Using the Design and Build Procurement System	5	4	3	2	1
2.2	Enhancing the working relationship between consultant, contractor and client	5	4	3	2	1
2.3	Extraordinarily longer Defects Liability Period	5	4	3	2	1
2.4	Evaluating the design scheme with life-cycle costing technique	5	4	3	2	1
	Others, please specify:					

No.	Attribute (Please give your opinion in the context of the Hong Kong construction industry.)	Importance High← →Low				
3.0	**Design Layout**					
3.1	Adequate provision of access for the execution of maintenance tasks (both routine and periodic)	5	4	3	2	1
3.2	Avoid designing permanent fixations	5	4	3	2	1
3.3	Designing for minimum maintenance at height, underground or in confined space	5	4	3	2	1
3.4	Designing for safe maintenance at height, underground or in confined space	5	4	3	2	1
3.5	Allowing sufficient working space for labour and plant	5	4	3	2	1
	Others, please specify:					
4.0	**Materials**					
4.1	Choosing materials which require minimum maintenance	5	4	3	2	1
4.2	Avoid specifying materials which need complete replacement	5	4	3	2	1
4.3	Design has taken full account of climatic factors in choosing materials	5	4	3	2	1
4.4	Using materials which are available during the life of the building	5	4	3	2	1
4.5	Designers have taken full account in and balanced the locality, economics and building technique in choosing material	5	4	3	2	1
	Others, please specify:					
5.0	**Flexibility**					
5.1	Designing for interchangeability	5	4	3	2	1
5.2	Design which enables the use of readily available alternative materials or components of similar performance, costs and appearance	5	4	3	2	1
	Others, please specify:					
6.0	**Innovations**					
6.1	Design to allow for innovative construction techniques and use of innovative materials which are well tested	5	4	3	2	1
	Others, please specify:					
7.0	**Weather**					
7.1	Design option which will minimize the effect of weather on maintenance	5	4	3	2	1
7.2	Design to allow maintenance to be deferred until desirable weather or rescheduled to accommodate planned maintenance	5	4	3	2	1
	Others, please specify:					
8.0	**Specification and Detailing**					
8.1	Specifying in the contract document as detail as possible the necessary construction materials and construction methods	5	4	3	2	1
	Others, please specify:					
9.0	**Disassembly/ assembly, Installation**					
9.1	Allowing easy connection/ interfacing between components	5	4	3	2	1
9.2	Allowing easy installation without complicated fixings	5	4	3	2	1
	Others, please specify:					

No	Attribute (Please give your opinion in the context of the Hong Kong construction industry.)	Importance High← →Low				
10.0	**Personnel**					
10.1	Designers or architects have received training in maintainability	5	4	3	2	1
10.2	A clear design brief from the client in maintenance performance	5	4	3	2	1
10.3	Designers have access to the information, specifications and data about the performance of materials and components	5	4	3	2	1
	Others, please specify:					
11.0	**Maintenance Plants and Equipments**					
11.1	Considering the availability of maintenance equipment right from the design stage and application of automatic machines	5	4	3	2	1
11.2	Sizes and weights of materials and components are safe for workers to handle using commonly available plants	5	4	3	2	1
11.3	Designing for the optimum use of maintenance equipment and plant	5	4	3	2	1
11.4	Maximize the use of automatic machines as daily maintenance equipments	5	4	3	2	1
	Others, please specify:					
12.0	**Other Resources**					
12.1	Material manual about the durability of materials, routine maintenance and performance	5	4	3	2	1
	Others, please specify:					
13.0	**Diagnosability**					
13.1	Designing adequate access for purpose of inspection	5	4	3	2	1
13.2	The choice of materials and components which enable diagnosis to be carried out in an inexpensive and time-saving manner using handy methods and shows immediate result	5	4	3	2	1
	Others, please specify:					
14.0	**Standardization**					
14.1	Uncomplicated geometry, layout and shape of components	5	4	3	2	1
14.2	Allowing modular layout of components	5	4	3	2	1
14.3	Allowing a high degree of standardization and repetition of components used but review the standards regularly	5	4	3	2	1
14.4	Use of standard details with lots of repetition such that relatively low skill level is required	5	4	3	2	1
	Others, please specify:					
15.0	**Prefabrication**					
15.1	Choice of materials/ components allowing prefabrication of components off site	5	4	3	2	1
	Others, please specify:					
Part B: Practices or Features Contributing to Maintainability in Post Occupancy Stages						
16.0	**Management and Documentations**					
16.1	Keeping coordinated drawings, manuals and maintenance handbook in custody by the property owner	5	4	3	2	1
16.2	Documentations (e.g. specifications, drawings, etc) in custody are detailed, unambiguous, misunderstanding free and the most updated	5	4	3	2	1

No.	**Attribute** (Please give your opinion in the context of the Hong Kong construction industry.)	**Importance**				
		High← →Low				
16.3	With as-built drawings showing the accurate position of works	5	4	3	2	1
16.4	Operation and maintenance guidelines with the information on repair and replacement procedures	5	4	3	2	1
16.5	Proper routine and periodic maintenance (e.g. cleaning and repair) with records in log book	5	4	3	2	1
16.6	Implementation of proper maintenance management programme	5	4	3	2	1
	Others, please specify:					
17.0	**Personnel**					
17.1	Proficiency of staffs in carrying out maintenance works and diagnosis	5	4	3	2	1
17.2	Providing a hazardous free environment for personnel to execute maintenance works, for example, precautionary measures for proximity of high voltage lines, no harmful gaseous content	5	4	3	2	1
	Others, please specify:					
18.0	**Environmental Consideration**					
18.1	Causing less environmental nuisance (e.g. noise, vibration, waste water, chemical waste and dust) to the surroundings in the course of maintenance	5	4	3	2	1
18.2	Allowing less wet trades in situ	5	4	3	2	1
18.3	Optimizing the mix of offsite and onsite works	5	4	3	2	1
	Others, please specify:					
19.0	**Alteration**					
19.1	Avoid the presence of Unauthorized Building Works	5	4	3	2	1
	Others, please specify:					

END OF PART I

APPENDIX B

SAMPLE OF SURVEY QUESTIONS

MAINTAINABILITY OF DIFFERENT CONSTRUCTION SYSTEMS

PART II: SURVEY ON THE MAINTAINABILITY OF DIFFERENT CONSTRUCTION SYSTEMS

Please write the appropriate number in each box below indicating your views of the following construction systems with respect to building maintainability. A scale of 1 to 5 is used where:

5 : Very HIGH contributions towards maintainable designs

4 to 2 : Intermediate levels between 5 and 1

1 : Very LOW contributions towards maintainable designs

Construction Systems						
Structural Frame	RC frame	5	4	3	2	1
	Load bearing or shear walls that replace columns	5	4	3	2	1
	In-situ RC core wall with RC external frame	5	4	3	2	1
	In-situ RC core wall with structural steel external frame (composite structure)	5	4	3	2	1
	Mega-structures using pure structural steel frame	5	4	3	2	1
	Others, please specify	5	4	3	2	1
Slab and Roof	RC Slab	5	4	3	2	1
	Composite Floor with RC topping	5	4	3	2	1
	Others, please specify	5	4	3	2	1
Building Envelope	Concrete Infill Wall	5	4	3	2	1
	Concrete Block/ Brick	5	4	3	2	1
	Curtain Wall (Glazed)	5	4	3	2	1
	Precast Concrete Cladding	5	4	3	2	1
	Metal Cladding	5	4	3	2	1
	GRC/ GRP Cladding	5	4	3	2	1
	Others, please specify	5	4	3	2	1

END OF PART II

APPENDIX C

SAMPLE OF SURVEY QUESTIONS

MAINTAINABILITY OF DIFFERENT FINISHING SYSTEMS

PART III: SURVEY ON THE MAINTAINABILITY OF DIFFERENT FINISHING SYSTEMS

Please write the appropriate number in each box below indicating your views of the effects of the following types of finishes or construction at different locations of a building on building maintainability. A scale of 1 to 5 is used where:

5 : Very HIGH contributions towards maintainable designs
4 to 2 : Intermediate levels between 5 and 1
1 : Very LOW contributions towards maintainable designs

Example

Types of finishes / Locations	False ceiling – Mineral fibre	False ceiling – Aluminum panels	Metal suspended ceiling (e.g. metal mesh ceiling)	Dry lining ceiling (e.g. plasterboard)	Plaster and painting	Wall paper	Others (please suggest)
Internal Ceilings	5	2	**An example only and no need to fill in this row**				

Internal Ceilings Finishes

Types of finishes / Locations	False ceiling – Mineral fibre	Metal suspended ceiling (e.g. Aluminum Panels, Egg Crate)	Dry lining ceiling (e.g. plasterboard)	Plaster and painting	Wall paper	Others (please suggest)
Internal Ceilings						

Internal Walls Finishes

Types of finishes / Locations	Wall Tiles (e.g. Glazed ceramic tiles, glass mosaic tiles (vitrified))	Marble and Granite Slabs	Timber (e.g. Plywood, Plaster-board)	Glass	Plaster and painting	Fairface concrete	Wall paper	Others (please suggest)
Internal Walls								

Internal Floors Finishes

Types of finishes / Locations	Granolithic finish	Terrazzo	Ceramic Tiles	Quarry Tiles	Concrete Tiles	Flexible PVC	Carpet	Marble or granite paving slabs	Timber Boarding	Raised Flooring	Others (please suggest)
Internal Floors											

External Walls Finishes

Types of finishes / Locations	Ceramic/ Mosaic tiles	Marble and granite	Traditional Masonry	Fairface concrete	Plaster and painting	Timber	Metal Cladding	Glass (in form of curtain wall or other)	Others (please suggest)
External Wall									

Roof

Construction Type / Locations	Tiles on asphalt roofing	Tiles on Bitumen Felt Built-Up Roofing	Tiles on Bituminous Emulsion Roofing	Corrugated steel sheet/ aluminum	Rolled copper sheet/ strip/ foil	Milled sheet	Others (please suggest)
Maintainability of Roof							

In view of maintainability assessment of building finishes applied at different locations, would you agree with the weightings thereunder regarding the relative importance of these locations and maintenance requirement contributing to a maintainable building design?

	Weightings in Maintainability	Locations of finishes
60%	20%	Internal walls
	20%	Internal floors
	20%	Internal ceilings
40%	30%	External walls
	10%	Roof
	∑=100%	

Comments on the weightings on left hand side (please tick the appropriate box):

☐ I would agree with the weightings on the left.

☐ I would not agree with the above weightings and more preferable weightings are indicated below:

Weightings in Maintainability	Locations of finishes	Further comments:
________%	Internal walls	________________
________%	Internal floors	________________
________%	Internal ceilings	________________
________%	External walls	________________
________%	Roof	________________

END OF PART III

APPENDIX D

SAMPLE OF SURVEY QUESTIONS

BUILDING SERVICES FEATURES AFFECTING MAINTAINABILITY

Part IV: SURVEY ON THE BUILDING SERVICES FEATURES AFFECTING MAINTAINABILITY

Please circle the appropriate number in each box indicating your views. Again, a scale of 1 to 5 is used where:

5 : Very HIGH contributions towards maintainable buildings
4 to 2 : Intermediate levels between 5 and 1
1 : Very LOW contributions towards maintainable buildings

Aspects of Building Services System in terms of Maintainability	Importance High←				→ Low
Location and Space					
Placing components and equipments in a suitable space and location (e.g. avoid locating wet pipes over electrical installation, place bulky items on ground level)	5	4	3	2	1
Good layout of equipment in plant rooms to maximize the utilization of space and for maintenance to be carried out without difficulty	5	4	3	2	1
Adequate headroom for the sake of maintenance (e.g. replacement, inspection)	5	4	3	2	1
Ease of access	5	4	3	2	1
Disassembly/ Assembly					
Adopting systems which enable easy opening, fastening of parts and components	5	4	3	2	1
Standardization					
Use of standard and universal components inside the system	5	4	3	2	1
Simplicity					
Equilibrium between minimal replacement and minimum number of components/ assemblies	5	4	3	2	1
Diagonsability					
Provision of monitoring system for proper operation	5	4	3	2	1
Building services adopted with high diagonsability such that ordinary staffs can report the potential failure	5	4	3	2	1
Modularity and Availability					
Equipment design which enables only the failed parts to be repaired/ replaced	5	4	3	2	1
Parts or compatible replacements are always available within the life of systems	5	4	3	2	1
Documentation and Details					
Adequate installation details of the systems (e.g. penetration details, embedment details and details of supports)	5	4	3	2	1
Keeping the details of the systems	5	4	3	2	1
Trace of actual location of services system in as-built drawings/ photographs	5	4	3	2	1
Keeping log books with regular update for maintenance	5	4	3	2	1
Operational and maintenance guidelines	5	4	3	2	1
Clear cable management and identification	5	4	3	2	1
Coordination					
Coordination between services systems and building systems	5	4	3	2	1
Environment					
Hazardous free environment for maintenance work	5	4	3	2	1

Aspects of Building Services System in terms of Maintainability	**Importance** **High← → Low**				
Minimal requirement of hoisting of parts, or adequate provision for temporary cranage	5	4	3	2	1
Others, please specify					

APPENDIX E

SAMPLE OF SURVEY QUESTIONS

SITE/ LOCATIONAL FACTORS AFFECTING MAINTAINABILITY

PART V: SURVEY ON THE SITE/ LOCATIONAL FACTORS AFFECTING MAINTAINABILITY

Please circle the appropriate number in each box indicating your views. Again, a scale of 1 to 5 is used where:

5 : Very HIGH contributions towards maintainable designs
4 to 2 : Intermediate levels between 5 and 1
1 : Very LOW contributions towards maintainable designs

Site/ Locational Factors		Importance High←				→Low
1.0	**Surrounding Environment**					
1.1	With temporary storage areas for maintenance works, repair, building rehabilitation, etc	5	4	3	2	1
1.2	Adequate working space for safe maintenance, building rehabilitation, etc	5	4	3	2	1
1.3	Not abutting to vulnerable buildings/ structures such as old dilapidated buildings	5	4	3	2	1
1.4	Not adjacent to occupied buildings/ structure	5	4	3	2	1
1.5	Not abutting other construction site(s)	5	4	3	2	1
1.6	Not abutting pedestrian pavement(s)	5	4	3	2	1
1.7	Buildings not on slope(s)	5	4	3	2	1
1.8	With open space	5	4	3	2	1
1.9	With access and exit roads for trucks and plants	5	4	3	2	1
1.10	Public utilities, e.g. gaseous pipes, electrical/ telecommunication cables etc, underneath the site	5	4	3	2	1
1.11	Not adjacent to water-containing areas e.g. sea, river, reservoir or lake	5	4	3	2	1
1.12	No difficulties in setting up hoardings, scaffolding or shoring to adjacent buildings	5	4	3	2	1
2.0	**Access**					
2.1	Allowing for access and movement of any necessary plants with adequate turning radius	5	4	3	2	1
3.0	**Hazard-free Environment**					
3.1	No presence of hazardous substance inside the site e.g. asbestos	5	4	3	2	1
3.2	Potentially hazardous establishments near the building, e.g. underground cable or gas/ petrol storage	5	4	3	2	1
4.0	**Underground Maintenance**					
4.1	Safety consideration or measures incorporated into design	5	4	3	2	1
Site/ Locational Factors		**Importance High←**				**→Low**
4.2	Adequate considerations incorporated into design to minimize design faults underground (e.g. overcoming potential problems of water ingress)	5	4	3	2	1
5.0	**Preservation**					
5.1	Preservation of trees, monuments, etc adjacent to the building	5	4	3	2	1
5.2	Preservation of trees, monuments, etc within the building	5	4	3	2	1
6.0	**Maintenance program, design, etc overcoming restrictions imposed by the government/ the client/ the users, etc.**					
6.1	Working hour restrictions	5	4	3	2	1
6.2	Construction sequence restrictions	5	4	3	2	1

7.0	**Others**					
	Please specify:					

APPENDIX F

SAMPLE OF SURVEY QUESTIONS

WEIGHTINGS OF COMPONENTS AMONGST SECTION 1 TO 5 OF QUANTITATIVE SURVEYS IN THE ASSESSMENT MODEL

PART VI: SURVEY ON THE WEIGHTINGS OF COMPONENTS COMPRISING MAINTAINABILITY ASSESSMENT MODEL

If weightings have to be assigned into the following components for their contribution towards the overall building maintainability, how would you weight the relative importance of these components (in percentage)?

Components	Suggested % (Pl. fill in whole no.)	Remarks (if any)
Structural System (Part II)	%	
Slab System (Part II)	%	
Building Envelope System (Part II)	%	
Finishes (Part III)	%	
Pre and post occupancy measures contributing to good maintainability (Part I)	%	
Building Services Systems (Part VI)	%	
Site/ Locational Factors (Part V)	%	
Others	%	
Total:	**100%**	

END OF THE INTERVIEW

THANK YOU VERY MUCH FOR YOUR CONTRIBUTION!

APPENDIX G

SURVEY RESULTS

DISTRIBUTION OF SCORES OF PRE-OCCUPANCY PRACTICES OR FEATURES AFFECTING BUILDING MAINTAINABILITY

Rank	Pre-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
1	**Diagnosability**	**0.00**	**3.85**	**7.69**	**88.46**	**0.908**
	• Designing adequate access for purpose of inspection	0.00	0.00	7.69	92.31	0.650
	• The choice of materials and components which enable diagnosis to be carried out in an inexpensive and time-saving manner using handy methods and shows immediate result	0.00	7.69	7.69	84.62	1.166
2	**Personnel**	**0.00**	**5.13**	**17.95**	**76.92**	**0.858**
	• Designers have access to the information, specifications and data about the performance of materials and components	0.00	0.00	15.38	84.62	0.689
	• Designers or architects have received training in maintainability	0.00	7.69	15.38	76.92	0.987
	• A clear design brief from the client in maintenance performance	0.00	7.69	23.08	69.23	0.899

Appendix G: Table Showing Distribution of Scores of Pre-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee deleted a particular item) (To be cont'd)

(Cont'd)

Rank	Pre-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
3	**Design Layout**	**6.15**	**9.23**	**16.92**	**73.85**	**0.924**
	• Adequate provision of access for the execution of maintenance tasks (both routine and periodic)	0.00	0.00	0.00	100.00	0.376
	• Allowing sufficient working space for labour and plant	0.00	0.00	7.69	92.31	0.630
	• Designing for safe maintenance at height, underground or in confined space	0.00	0.00	15.38	84.62	0.751
	• Designing for minimum maintenance at height, underground or in confined space	7.69	7.69	23.08	69.23	1.316
	• Avoid designing permanent fixations	23.08	38.46	38..46	23.08	1.548
4	**Project Team Structure**	**3.85**	**15.38**	**19.23**	**65.38**	**1.170**
	• Participation of experienced maintenance manager during the design process	0.00	0.00	15.38	84.62	0.768

Appendix G: Table Showing Distribution of Scores of Pre-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee deleted a particular item) (To be cont'd)

(Cont'd)

Rank	Pre-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	**<3**	**3**	**>3**	
	• Future maintenance manger involves in the supervision of construction works to facilitate future maintenance tasks	7.69	30.77	23.08	46.15	1.573
5	**Materials**	**3.08**	**10.77**	**21.54**	**67.69**	**1.102**
	• Design has taken full account of climatic factors in choosing materials	0.00	0.00	0.00	100.00	0.519
	• Designers have taken full account in and balanced the locality, economics and building technique in choosing material	0.00	7.69	15.38	76.92	0.801
	• Choosing materials which require minimum maintenance	7.69	15.38	7.69	76.92	1.589
	• Using materials which are available during the life of the building	0.00	15.38	38.46	46.15	1.198
	• Avoid specifying materials which need complete replacement	0.00	15.38	46.15	38.46	1.405

Appendix G: Table Showing Distribution of Scores of Pre-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee deleted a particular item) (To be cont'd)

(Cont'd)

Rank	Pre-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
6	**Flexibility**	**0.00**	**7.69**	**30.77**	**61.54**	**1.132**
	• Design which enables the use of readily available alternative materials or components of similar performance, costs and appearance	0.00	7.69	23.08	69.23	1.144
	• Designing for interchangeability	0.00	7.69	38.46	53.85	1.121
7	**Standardization**	**1.92**	**7.69**	**21.15**	**71.15**	**1.096**
	• Allowing modular layout of components	0.00	7.69	7.69	84.62	0.987
	• Use of standard details with lots of repetition such that relatively low skill level is required	0.00	7.69	23.08	69.23	1.092
	• Allowing a high degree of standardization and repetition of components used but review the standards regularly	0.00	7.69	30.77	61.54	1.044
	• Uncomplicated geometry, layout and shape of components	7.69	7.69	23.08	69.23	1.261

Appendix G: Table Showing Distribution of Scores of Pre-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee deleted a particular item) (To be cont'd)

(Cont'd)

Rank	Pre-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
8	**Maintenance Plants and Equipments**	**3.85**	**9.62**	**23.08**	**67.31**	**1.061**
	• Considering the availability of maintenance equipment right from the design stage, Application of automatic machines	0.00	0.00	7.69	92.31	0.801
	• Designing for the optimum use of maintenance equipment and plant	0.00	0.00	30.77	69.23	0.689
	• Sizes and weights of materials and components are safe for workers to handle using commonly available plants	0.00	15.38	15.38	69.23	1.182
	• Maximize the use of automatic machines as daily maintenance equipments	15.38	23.08	38.46	38.46	1.573
9	**Disassembly/ assembly, Installation**	**0.00**	**15.38**	**19.23**	**65.38**	**1.298**
	• Allowing easy connection// interfacing between components	0.00	15.38	15.38	69.23	1.266
	• Allowing easy installation without complicated fixings	0.00	15.38	23.08	61.54	1.330

Appendix G: Table Showing Distribution of Scores of Pre-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee deleted a particular item) (To be cont'd)

(Cont'd)

Rank	Pre-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
10	**Other Resources**	**7.69**	**15.38**	**23.08**	**61.54**	**1.391**
	• Material manual about the durability of materials, routine maintenance and performance	7.69	15.38	23.08	61.54	1.391
11	**Weather**	**0.00**	**11.54**	**30.77**	**57.69**	**1.265**
	• Design option which will minimize the effect of weather on maintenance	0.00	7.69	30.77	61.54	1.166
	• Design to allow maintenance to be deferred until desirable weather or rescheduled to accommodate planned maintenance	0.00	15.38	30.77	53.85	1.363
12	**Specification and Detailing**	**7.69**	**23.08**	**15.38**	**61.54**	**1.387**
	• Specifying in the contract document as detail as possible the necessary construction materials and construction methods	7.69	23.08	15.38	61.54	1.387

Appendix G: Table Showing Distribution of Scores of Pre-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee deleted a particular item) (To be cont'd)

(Cont'd)

Rank	Pre-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
13	**Prefabrication**	**0.00**	**15.38**	**61.54**	**23.08**	**1.068**
	• Choice of materials/ components allowing prefabrication of components off site	0.00	15.38	61.54	23.08	1.068
14	**Procurement System**	**13.46**	**28.85**	**26.92**	**44.23**	**1.472**
	• Evaluating the design scheme with life-cycle costing technique	7.69	7.69	30.77	61.54	0.927
	• Enhancing the working relationship between consultant, contractor and client	23.08	23.08	0.00	76.92	1.878
	• Extraordinary longer Defects Liability Period	15.38	46.15	30.77	23.08	1.758
	• Using the Design and Build Procurement System	0.477	38.46	46.15	15.38	1.325
15	**Innovations**	**7.69**	**38.46**	**38.46**	**23.08**	**1.193**
	• Design to allow for innovative construction techniques and use of innovative materials which are well tested	7.69	38.46	38.46	23.08	1.193

Appendix G: Table Showing Distribution of Scores of Pre-occupancy Practices or Features Affecting Building Maintainability

APPENDIX H

SURVEY RESULTS

DISTRIBUTION OF SCORES OF POST-OCCUPANCY PRACTICES OR FEATURES AFFECTING BUILDING MAINTAINABILITY

Rank	Post-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
1	**Personnel**	**0.00**	**0.00**	**7.69**	**92.31**	**0.648**
	• Proficiency of staffs in carrying out maintenance works and diagnosis	0.00	0.00	0.00	100.00	0.519
	• Providing a hazardous free environment for maintenance work, for example, precautionary measures for proximity of high voltage lines, no harmful gaseous content	0.00	0.00	15.38	84.62	0.776
2	**Alteration**	**0.00**	**0.00**	**15.38**	**84.62**	**0.768**
	• Avoid the presence of unauthorized building works	0.00	0.00	15.38	84.62	0.768
3	**Management and Documentations**	**1.28**	**2.56**	**3.85**	**93.59**	**0.774**
	• Implementation of proper maintenance management programme	0.00	0.00	0.00	100.00	0.480
	• Proper routine and periodic maintenance (e.g. cleaning and repair) with records in log book	0.00	0.00	0.00	100.00	0.519

Appendix H: Table Showing Distribution of Scores of Post-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee has deleted a particular item) (Cont'd)

Rank	Post-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
	• With as-built drawings showing the accurate position of works	0.00	0.00	7.69	92.31	0.660
	• Keeping coordinated drawings, manuals and maintenance handbook in custody by the property owner	0.00	7.69	0.00	92.31	0.870
	• Documentations (e.g. specifications, drawings, etc) in custody are detailed, unambiguous, misunderstanding free and the most updated	0.00	0.00	15.38	84.62	0.751
	• Operational and maintenance guidelines developed by the contractors for the information on repair and replacement procedures	7.69	7.69	0.00	92.31	1.363
4	**Environmental Consideration**	**10.26**	**41.03**	**48.72**	**10.26**	**1.277**
	Causing less environmental nuisance (e.g. noise, vibration, waste water, chemical waste and dust) to the surroundings in the course of maintenance	0.00	38.46	61.54	0.00	0.862

Appendix H: Table Showing Distribution of Scores of Post-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee has deleted a particular item) (Cont'd)

(Cont'd)

Rank	Post-occupancy Practices or Features Affecting Maintainability	Percentage of Interviewees Scoring				Standard Deviation
		0	<3	3	>3	
	Optimizing the mix of offsite work and onsite work by the maintenance manager	15.38	38.46	46.15	15.38	1.498
	Allowing less wet trades in situ	15.38	46.15	38.46	15.38	1.472

Appendix H: Table Showing Distribution of Scores of Post-occupancy Practices or Features Affecting Building Maintainability (Score of 0 means the interviewee has deleted a particular item)

APPENDIX I

SURVEY RESULTS

FACTOR ANALYSIS RESULT WITH VARIMAX ROTATION

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	19.369	37.979	37.979	19.369	37.979	37.979	12.694	24.891	24.891
2	8.145	15.970	53.949	8.145	15.970	53.949	8.701	17.061	41.952
3	6.877	13.484	67.433	6.877	13.484	67.433	7.307	14.328	56.279
4	3.962	7.769	75.202	3.962	7.769	75.202	4.913	9.633	65.912
5	3.113	6.103	81.305	3.113	6.103	81.305	4.409	8.646	74.557
6	2.546	4.991	86.296	2.546	4.991	86.296	3.846	7.540	82.098
7	2.100	4.118	90.414	2.100	4.118	90.414	3.189	6.253	88.351
8	1.776	3.482	93.896	1.776	3.482	93.896	2.127	4.170	92.521
9	1.417	2.779	96.675	1.417	2.779	96.675	2.119	4.154	96.675

Extraction Method: Principal Component Analysis.

Appendix I: Table showing the Factor Analysis result with Varimax rotation (N=13) (Cont'd)

(Cont’d)

Rotated Component Matrix[a]

	Component								
	1	2	3	4	5	6	7	8	9
QO2	.963								
QO4	.917								
QO1	.915								
QK1	.911								
QO3	.868								
QL1	.840								
QC3	.831								
QK2	.821								
QA2	.742								
QN2	.738								
QL2	.732	.574							
QQ4	.715								
QE1	.639								
QE2	.636						.615		
QS1	.634							-.502	
QD4	.614						.606		
QA1	.589								
QR2	.569								
QQ1		.944							
QQ3		.939							
QQ2		.805							
QJ1		.763							
QJ2		.753							
QE3		.676							
QP1		.650							
QG1									
QH1			.974						
QM1			.935						
QG2			.913						
QD2			.901						
QB3			.723						
QD1		.673	.687						

Appendix I: Table showing the Factor Analysis result with Varimax rotation (N=13) (Cont’d)

(Cont’d)

	Component								
	1	2	3	4	5	6	7	8	9
QB2		.663	.672						
QL4		.616	.669						
QB1		.582	.605						
QN1				.889					
QC4				.838					
QC1				.822					
QC5				.700					
QL3	.533			.575					
QQ6					.941				
QQ5					.917				
QK3					.797				
QT1					.684				
QR1									
QS2						-.872			
QS3						-.815			
QB4						.613			
QD5							.782		
QC2								.712	
QD3									.701

Extraction Method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization.

a. Rotation converged in 14 iterations.

Appendix I: Table showing the Factor Analysis result with Varimax rotation (N=13) (Cont'd)

APPENDIX J

SURVEY RESULTS

DISTRIBUTION OF SCORES OF RELATIVE IMPORTANCE OF CONSTRUCTION SYSTEMS ON MAINTAINABILITY

Construction Systems	Percentage of Interviewees Scoring			Standard Deviation
	<3	=3	>3	
Structural Frame				
In-situ RC Core Wall with RC External Frame	11.11	22.22	66.67	1.130
In-situ RC Core Wall with Structural Steel External Frame (i.e. Composite Structure)	11.11	33.33	55.56	1.236
Mega-structures using Pure Structural Steel Frame	11.11	44.44	44.44	1.333
RC Frame	11.11	44.44	44.44	1.236
Load Bearing or Shear Walls that Replace Columns	22.22	44.44	33.33	1.167
Slab and Roof				
RC Slab	11.11	44.44	44.44	1.014
Composite Floor with RC Topping	22.22	33.33	44.44	0.667
Building Envelope				
Curtain Wall (Glazed)	0.00	33.33	66.67	0.782
Concrete Block/ Concrete Brick	0.00	44.44	55.56	0.928
Concrete Infill Wall	0.00	55.56	44.44	0.726
Metal Cladding	0.00	55.56	44.44	0.726
Precast Concrete Cladding	11.11	44.44	44.44	1.014
GRC/ GRP Cladding	11.11	55.56	33.33	1.014

Appendix J: Table Showing Distribution of Scores of Relative Importance of Construction Systems on Maintainability

APPENDIX K

SURVEY RESULTS

DISTRIBUTION OF SCORES OF RELATIVE MAINTAINABILITY OF FINISHING SYSTEMS

Locations	Finishing Systems	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
Internal Ceilings	• False Ceiling (Mineral Fibre)	36.36	27.27	36.36	1.221
	• Metal Suspended Ceiling (e.g. Aluminum Panels, Egg Crate)	0.00	18.18	81.82	0.751
	• Dry Lining Ceiling (e.g. plasterboard)	72.73	18.18	9.09	0.905
	• Plaster and Painting	27.27	45.45	27.27	1.221
	• Wall Paper	63.64	36.36	0.00	0.944
Internal Wall	• Wall Tiles	18.18	18.18	63.64	1.104
	• Marble and Granite	27.27	9.09	63.64	1.128
	• Timber (e.g. Plywood, Plaster-board)	45.45	45.45	9.09	0.934
	• Glass	36.36	18.18	45.45	1.250
	• Plaster and Painting	54.55	18.18	27.27	1.079
	• Fairface Concrete	54.55	27.27	18.18	1.433
	• Wall Paper	72.73	27.27	0.00	0.831
Internal Floors	• Granolithic Finish	54.55	18.18	27.27	1.128
	• Terrazzo	45.45	18.18	36.36	1.191
	• Ceramic Tiles	18.18	27.27	54.55	1.120
	• Quarry Tiles	27.27	36.36	36.36	1.136

Appendix K: Table Showing Distribution of Scores of Relative Maintainability of Finishing Systems (To be cont'd)

(Cont'd)

Locations	Finishing Systems	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
Internal Floors	• Concrete Tiles	45.45	27.27	27.27	1.272
	• Flexible PVC	36.36	54.55	9.09	0.646
	• Carpet	45.45	36.36	18.18	1.368
	• Marble or Granite slabs	27.27	18.18	54.55	1.128
	• Timber Boarding	27.27	63.64	9.09	0.924
	• Raised Flooring	27.27	18.18	54.55	1.368
External Wall	• Ceramic/ Mosaic Tiles	36.36	18.18	45.45	1.079
	• Marble and Granite	27.27	18.18	54.55	1.191
	• Traditional Masonry	27.27	36.36	36.36	1.136
	• Fairface Concrete	54.55	0.00	45.45	1.695
	• Plaster and Painting	54.55	9.09	36.36	1.250
	• Timber	90.91	9.09	0.00	0.688
	• Metal Cladding	9.09	36.36	54.55	1.036
	• Glass (in form of curtain wall or other)	9.09	36.36	54.55	0.820
Roof	• Tiles on Asphalt Roofing	27.27	45.45	36.36	1.221

Appendix K: Table Showing Distribution of Scores of Relative Maintainability of Finishing Systems (To be cont'd)

(Cont'd)

Locations	Finishing Systems	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
Roof	• Tiles on Bitumen Felt Built-Up Roofing	18.18	36.36	45.45	0.924
	• Tiles on Bituminous Emulsion Roofing	18.18	63.64	18.18	0.831
	• Corrugated Steel Sheet/ Aluminum	27.27	36.36	36.36	1.136
	• Rolled Copper Sheet/ Strip/ Foil	54.55	18.18	27.27	1.293
	• Milled Sheet	54.55	18.18	27.27	1.293

Appendix K: Table Showing Distribution of Scores of Relative Maintainability of Finishing Systems

APPENDIX L

SURVEY RESULTS

DISTRIBUTION OF SCORES OF FEATURES AFFECTING MAINTAINABILITY OF BUILDING SERVICES SYSTEMS

Rank	Maintainable Features in Building Services Systems	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
1	**Disassembly/ Assembly**	**0.00**	**0.00**	**100.00**	**0.515**
	• Adopting systems which enable easy opening, fastening of parts and components	0.00	0.00	100.00	0.515
2	**Location and Space**	**0.00**	**6.25**	**93.75**	**0.617**
	• Ease of access	0.00	0.00	100.00	0.492
	• Adequate headroom for the sake of maintenance (e.g. replacement, inspection)	0.00	8.33	91.67	0.674
	• Placing components and equipments in a suitable space and location (e.g. avoid locating wet pipes over electrical installation, place bulky items on ground level)	0.00	8.33	91.67	0.651
	• Good layout of equipment in plant rooms to maximize the utilization of space and for maintenance to be carried out without difficulty	0.00	8.33	91.67	0.651

Appendix L: Table Showing Distribution of Scores of Features Affecting Maintainability of Building Services Systems (To be cont'd)

(Cont'd)

Rank	Maintainable Features in Building Services Systems	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
3	**Documentation and Details**	**0.00**	**11.11**	**88.89**	**0.689**
	• Operational and maintenance guidelines	0.00	0.00	100.00	0.492
	• Keeping log books with regular update for maintenance	0.00	8.33	91.67	0.669
	• Adequate installation details of the systems (e.g. penetration details, embedment details and details of supports)	0.00	16.67	83.33	0.778
	• Keeping the details of the systems	0.00	16.67	83.33	0.778
	• Trace of actual location of services system in as-built drawings/ photographs	0.00	16.67	83.33	0.793
	• Clear cable management and identification	0.00	8.33	91.67	0.622
4	**Environment**	**4.17**	**16.67**	**79.17**	**0.839**
	• Hazardous free environment for maintenance work	0.00	16.67	83.33	0.778

Appendix L: Table Showing Distribution of Scores of Features Affecting Maintainability of Building Services Systems (To be cont'd)

(Cont'd)

Rank	Maintainable Features in Building Services Systems	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
	• Minimal requirement of hoisting of parts, or adequate provision for temporary cranage	8.33	16.67	75.00	0.900
5	**Standardization**	**8.33**	**8.33**	**83.33**	**0.900**
	• Use of standard and universal components inside the system	8.33	8.33	83.33	0.900
6	**Diagonsability**	0.00	16.67	83.33	**0.636**
	• Provision of monitoring system for proper operation	0.00	16.67	83.33	0.669
	• Building services adopted with high diagonsability such that ordinary staffs can report the potential failure	0.00	16.67	83.33	0.603
7	**Simplicity**	**0.00**	**16.67**	**83.33**	**0.603**
	• Equilibrium between minimal replacement and minimum number of components/ assemblies	0.00	16.67	83.33	0.603

Appendix L: Table Showing Distribution of Scores of Features Affecting Maintainability of Building Services Systems

(To be cont'd)

(Cont'd)

Rank	Maintainable Features in Building Services Systems	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
8	**Coordination**	**0.00**	**25.00**	**75.00**	**0.739**
	• Coordination between services systems and building systems	0.00	25.00	75.00	0.739
9	**Modularity and Availability**	0.00	**20.83**	**79.17**	**0.636**
	• Equipment design which enables only the failed parts to be repaired/ replaced	0.00	16.67	83.33	0.603
	• Parts or compatible replacements are always available within the life of systems	0.00	25.00	75.00	0.669

Appendix L: Table Showing Distribution of Scores of Features Affecting Maintainability of Building Services Systems

APPENDIX M

SURVEY RESULTS

DISTRIBUTION OF SCORES OF SITE/ LOCATIONAL FACTORS AFFECTING BUILDING MAINTAINABILITY

Rank	Site/ Locational Factors	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
1	**Underground Maintenance**	**0.00**	**9.09**	**90.90**	**0.660**
	• Adequate considerations incorporated into design to minimize design faults underground (e.g. overcoming potential problems of water ingress)	0.00	9.09	90.90	0.467
	• Safety consideration or measures incorporated into design	0.00	9.09	90.90	0.674
2	**Access**	**0.00**	**27.27**	**72.73**	**0.775**
	• Allowing for access and movement of any necessary plants with adequate turning radius	0.00	27.27	72.73	0.775
3	**Hazard-free Environment**	**18.18**	**13.64**	**68.18**	**1.543**
	• No presence of hazardous substance inside the site e.g. asbestos	18.18	0.00	81.82	1.578
	• Potentially hazardous establishments near the building, e.g. underground cable or gas/ petrol storage	18.18	27.27	54.55	1.508

Appendix M: Table Showing Distribution of Scores of Site/ Locational Factors Affecting Building Maintainability (To be cont'd)

(Cont'd)

Rank	Site/ Locational Factors	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
4	**Preservation**	**18.18**	**31.82**	**50.00**	**1.210**
	• Preservation of trees, monuments, etc within the building	18.18	36.36	45.46	1.214
	• Preservation of trees, monuments, etc adjacent to the building	18.18	27.27	54.55	1.206
5	**Surrounding Environment**	20.46	28.03	51.52	1.202
	• Adequate working space for safe maintenance, building rehabilitation, etc	0.00	9.09	90.91	0.603
	• With access and exit roads for trucks and plants	9.09	9.09	81.82	0.831
	• No difficulties in setting up hoardings, scaffolding or shoring to adjacent buildings	9.09	18.18	72.73	1.293
	• With temporary storage areas for maintenance works, repair, building rehabilitation, etc	9.09	35.35	54.55	0.820

Appendix M: Table Showing Distribution of Scores of Site/ Locational Factors Affecting Building Maintainability (To be cont'd)

(Cont'd)

Rank	Site/ Locational Factors	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
5	• Not abutting to vulnerable buildings/ structures such as old dilapidated buildings	9.09	27.27	63.64	1.433
	• Public utilities, e.g. gaseous pipes, electrical/ telecommunication cables etc, underneath the site	18.18	9.09	72.73	1.502
	• Not adjacent to water-containing areas e.g. sea, river, reservoir or lake	18.18	45.46	36.36	1.300
	• Buildings not on slope(s)	36.36	18.18	45.46	1.414
	• With open space	27.27	45.46	27.27	1.300
	• Not adjacent to occupied buildings/ structure	27.27	45.46	27.27	1.300
	• Not abutting pedestrian pavement(s)	45.46	27.27	27.27	1.348
	• Not abutting other construction site(s)	36.36	45.46	18.18	1.272

Appendix M: Table Showing Distribution of Scores of Site/ Locational Factors Affecting Building Maintainability (To be cont'd)

(Cont'd)

Rank	Site/ Locational Factors	Percentage of Interviewees Scoring			Standard Deviation
		<3	=3	>3	
6	**Restrictions on the Executive of Maintenance Tasks**	**9.09**	**45.46**	**45.46**	**1.272**
	• Working hour restrictions	9.09	45.46	45.46	1.272
	• Construction sequence restrictions	9.09	45.46	45.46	1.272

Appendix M: Table Showing Distribution of Scores of Site/ Locational Factors Affecting Building Maintainability

APPENDIX N

SAMPLE OF ASSESSMENT PROFORMA

PROFORMA OF THE BUILDING MAINTAINABILITY ASSESSMENT MODEL

MAINTAINABILITY ASSESSMENT PROFORMA

This proforma is designed to facilitate the data collection process in assessing the maintainability of buildings in Hong Kong, which is based on a quantitative model developed in 2008 by an undergraduate student in the University of Hong Kong. Having collected all the necessary data, they can be input into the electronic form of this proforma and definitely electrical processing can give rapid and accurate results. All data collected will be used solely for the state academic purpose. No identities of the project and its stakeholders will be released without prior consent.

For each building of your project, please use separate form and fill in the space available in the following tables. Leave it if not applicable

Project Title:	ABC Residential Development (Example)
Developer(s):	123 Development Limited
Main Contractor(s):	XYZ Construction Limited
Property Manager(s):	xyz Property Management Company
Type of Project:	Residential
Contract Sum:	HK$500M
Completion Date:	6.7.2005
Occupation Permit Issue Date:	3.9.2005
Building Age:	2.5 Years
Total Construction Floor Area (CFA):	56,954 M^2
Total Gross Floor Area (GFA):	38,743 M^2

N.B. Because two prototypes of the maintainability assessment model have been developed in this study, this proforma demonstrates the prototype which is without the assessment of the construction systems in the building, i.e. 5 areas in building will be assessed plus the 10 points for others maintainable features that are not included, the 5 areas include Finishing Systems (Section A), Pre and Post-occupancy Measures and Practices (Section B and C), Building Services Systems (Section D), Site and Locational Factors (Section E)

Section A: This section solicits the quantitative data of the building for maintainability assessment

(In this part, only approximate area or approximate distribution of proportions suffices the purpose of maintainability assessment)

Finishing Systems adopted:

Internal Ceilings	Plan area (m2)		Plan area in %
False ceiling – Mineral fibre			
False ceiling – Aluminum panels			
Metal suspended ceiling			
Dry lining ceiling			
Plaster and painting		**OR**	82.01%
Wall paper			17.99%
Others (please specify):			
Total:			100.00%

Internal Walls	Plan area (m2)		Elevation area in %
Wall Tiles			21.34%
Marble and Granite Slabs			
Timber			
Glass			
Plaster and painting		**OR**	56.90%
Fairface concrete			
Wall paper			21.76%
Others (please specify):			
Total:			100.00%

Internal Floor	Plan area (m2)		Plan area in %
Granolithic finish			2.02%
Terrazzo			4.67%
Ceramic Tiles			54.23%
Quarry Tiles			
Concrete Tiles			
Flexible PVC		**OR**	
Carpet			
Marble or granite paving slabs			39.08%
Timber Boarding			
Raised Flooring			
Others (please specify):			
Total:			100.00%

External Wall	Plan area (m2)		Elevation area in %
Ceramic/ Mosaic tiles			89.12%
Marble and granite			10.88%
Traditional Masonry			
Fairface concrete			
Plaster and painting			
Timber		**OR**	
Metal Cladding			
Glass (in form of curtain wall or other)			
Others (please specify):			
Total:			100.00%

Roofing	Plan area (m2)		Plan area in %
Tiles on asphalt roofing			
Tiles on Bitumen Felt Built-Up Roofing			100.00%
Tiles on Bituminous Emulsion Roofing			
Corrugated steel sheet/ aluminum			
Rolled copper sheet/ strip/ foil		**OR**	
Milled sheet			
Others (please specify):			
Total:			100.00%

Section B: This section is for assessment of the effects pre-occupancy practices and measures on maintainability

This section assesses the practices, measures and features during pre-occupancy stage which are used to enhance maintainability of buildings. Select the most appropriate estimated maximum proportion out of all details or the whole process of the building (i.e. Nil, 25%, 50%, 75% or 100%)

Pre-occupancy Practices/ Features	Estimated Maximum Proportion or Degree out of The Whole Process or All Details for the Building					
Involvement of Property Manager or Maintenance Manager	**Nil**	**25%**	**50%**	**75%**	**100%**	
Participation of experienced maintenance manager during the design process						50%
Future maintenance manger involves in the supervision of construction works to facilitate future maintenance tasks						Nil
Project Management and Procurement						
Using the Design and Build Procurement System						Nil
Enhancing the working relationship between consultant, contractor and client						100%
Extraordinarily longer Defects Liability Period						Nil
Evaluating the design scheme with life-cycle costing technique						100%
Design Layout						
Adequate provision of access for the execution of maintenance tasks (both routine and periodic)						75%
Avoid designing permanent fixations						25%
Designing for minimum maintenance at height, underground or in confined space						50%
Designing for safe maintenance at height, underground or in confined space						50%
Allowing sufficient working space for labour and plant						75%
Materials						
Choosing materials which require minimum maintenance						75%
Avoid specifying materials which need complete replacement						25%
Design has taken full account of climatic factors in choosing materials						75%
Using materials which are available during the life of the building						25%
Designers have taken full account in and balanced the locality, economics and building technique in choosing material						75%
Flexibility						
Designing for interchangeability						50%
Design which enables the use of readily available alternative materials or components of similar performance, costs and appearance						50%
Innovations						
Design to allow for innovative construction techniques and use of innovative materials which are well tested						50%
Weather						
Design option which will minimize the effect of weather on maintenance						25%
Design to allow maintenance to be deferred until desirable weather or rescheduled to accommodate planned maintenance						Nil
Specification and Detailing						
Specifying in the contract document as detail as possible the necessary construction materials and construction methods						100%

Pre-occupancy Practices/ Features	Estimated Maximum Proportion or Degree out of The Whole Process or All Details for the Building					
Disassembly/ assembly, Installation	**Nil**	**25%**	**50%**	**75%**	**100%**	
Allowing easy connection/ interfacing between components						75%
Allowing easy installation without complicated fixings						75%
Personnel						
Designers or architects have received training in maintainability						50%
A clear design brief from the client in maintenance performance						100%
Designers have access to the information, specifications and data about the performance of materials and components						50%
Maintenance Plants and Equipments						
Considering the availability of maintenance equipment right from the design stage and application of automatic machines						75%
Sizes and weights of materials and components are safe for workers to handle using commonly available plants						75%
Designing for the optimum use of maintenance equipment and plant						100%
Maximize the use of automatic machines as daily maintenance equipments						50%
Other Resources						
Material manual about the durability of materials, routine maintenance and performance						Nil
Diagnosability						
Designing adequate access for purpose of inspection						75%
The choice of materials and components which enable diagnosis to be carried out in an inexpensive and time-saving manner using handy methods and shows immediate result						50%
Standardization						
Uncomplicated geometry, layout and shape of components						75%
Allowing modular layout of components						75%
Allowing a high degree of standardization and repetition of components used but review the standards regularly						75%
Use of standard details with lots of repetition such that relatively low skill level is required						100%
Prefabrication						
Choice of materials/ components allowing prefabrication of components off site						75%

Section C: This section assesses the effect of post-occupancy practices and measures on maintainabilitv

This section assesses the practices, measures and features during post-occupancy stage which are used to enhance maintainability of buildings. Select the most appropriate estimated maiximum proportion out of all details or the whole prcoess of the building (i.e. Nil, 25%, 50%, 75% or 100%)

Post-occupancy Practices/ Features	Estimated Maximum Proportion or Degree out of The Whole Process or All Details for the Building					
Management and Documentations	**Nil**	**25%**	**50%**	**75%**	**100%**	
Keeping coordinated drawings, manuals and maintenance handbook in custody by the property owner						100%
Documentations (e.g. specifications, drawings, etc) in custody are detailed, unambiguous, misunderstanding free and the most updated						100%
With as-built drawings showing the accurate position of works						100%
Operation and maintenance guidelines with the information on repair and replacement procedures						75%
Proper routine and periodic maintenance (e.g. cleaning and repair) with records in log book						75%
Implementation of proper maintenance management						100%
Personnel						
Proficiency of staffs in carrying out maintenance works and diagnosis						75%
Providing a hazardous free environment for personnel to execute maintenance works, for example, precautionary measures for proximity of high voltage lines, no harmful gaseous content						100%
Environmental Consideration						
Causing less environmental nuisance (e.g. noise, vibration, waste water, chemical waste and dust) to the surroundings in the course of maintenance						100%
Allowing less wet trades in situ						100%
Optimizing the mix of offsite and onsite works						100%
Alteration						
Avoid the presence of Unauthorized Building Works						100%

Section D: This section assesses features in Building Services Systems that affect maintainabilitv

This section aims to assess the features in Building Services Systems which are used to enhance maintainability of buildings. Select the most appropriate estimated maximum proportion out of all details of the building or out of the whole process of the building (i.e. Nil, 25%, 50%, 75% or 100%)

Aspects of Building Services System	Estimated Maximum Proportion or Degree out of The Whole Process or All Details for the Building					
Location and Space	**Nil**	**25%**	**50%**	**75%**	**100%**	
Placing components and equipments in a suitable space and location (e.g. avoid locating wet pipes over electrical installation, place bulky items on ground level)						75%
Good layout of equipment in plant rooms to maximize the utilization of space and for maintenance to be carried out without difficulty						75%
Adequate headroom for the sake of maintenance (e.g. replacement, inspection)						75%
Ease of access						50%
Disassembly/ Assembly						
Adopting systems which enable easy opening, fastening of parts and components						50%
Standardization						
Use of standard and universal components inside the system						100%
Simplicity						
Equilibrium between minimal replacement and minimum number of components/ assemblies						50%
Diagonsability						
Provision of monitoring system for proper operation						75%
Building services adopted with high diagonsability such that ordinary staffs can report the potential failure						Nil
Modularity and Availability						
Equipment design which enables only the failed parts to be repaired/ replaced						100%
Parts or compatible replacements are always available within the life of systems						100%
Documentation and Details						
Adequate installation details of the systems (e.g. penetration details, embedment details and details of supports)						100%
Keeping the details of the systems						100%
Trace of actual location of services system in as-built drawings/ photographs						100%
Keeping log books with regular update for maintenance						100%
Operational and maintenance guidelines						Nil
Clear cable management and identification						100%
Coordination						
Coordination between services systems and building systems						100%
Environment						
Hazardous free environment for maintenance work						100%
Minimal requirement of hoisting of parts, or adequate provision for temporary cranage						50%

Section E: This section assesses site/ locational factors which may impact on maintainability

This section aims to assess the site/ locational factors in which presence of them which affect the maintainability of buildings. Select the most appropriate estimated maiximum proportion out of all details of the building (i.e. Nil, 25%, 50%, 75% or 100%), for this part, most of them are yes/no questions, in this case simply fill in Nil or 100% for no and yes respectively

Site/ Locational Factors	Estimated Maximum Proportion or Degree out of The Whole Process or All Details for the Building					
Surrounding Environment	**Nil**	**25%**	**50%**	**75%**	**100%**	
With temporary storage areas for maintenance works, repair, building rehabilitation, etc						Nil
Adequate working space for safe maintenance, building rehabilitation, etc						75%
Not abutting to vulnerable buildings/ structures such as old dilapidated buildings						Nil
Not adjacent to occupied buildings/ structure						Nil
Not abutting other construction site(s)						100%
Not abutting pedestrian pavement(s)						Nil
Buildings not on slope(s)						100%
With open space						Nil
With access and exit roads for trucks and plants						100%
Public utilities, e.g. gaseous pipes, electrical/ telecommunication cables etc, underneath the site						100%
Not adjacent to water-containing areas e.g. sea, river, reservoir or lake						Nil
No difficulties in setting up hoardings, scaffolding or shoring to adjacent buildings						Nil
Access						
Allowing for access and movement of any necessary plants with adequate turning radius						100%
Hazard-free Environment						
No presence of hazardous substance inside the site e.g.						Nil
Potentially hazardous establishments near the building, e.g. underground cable or gas/ petrol storage						Nil
Underground Maintenance						
Safety consideration or measures incorporated into design						100%
Adequate considerations incorporated into design to minimize design faults underground (e.g. overcoming potential problems of water ingress)						100%
Preservation						
Preservation of trees, monuments, etc adjacent to the building						Nil
Preservation of trees, monuments, etc within the building						Nil
Maintenance program, design, etc overcoming restrictions imposed by the government/ the client/ the users, etc.						
Working hour restrictions						Nil
Construction sequence restrictions						Nil

End of Assessment Proforma