ASSESSMENT OF MAINTAINABILITY DESIGN CRITERIA ON GOVERNMENT HOSPITAL BUILDINGS

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UNIVERSITI SAINS MALAYSIA
2018

ASSESSMENT OF MAINTAINABILITY DESIGN CRITERIA ON GOVERNMENT HOSPITAL BUILDINGS

by

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Thesis submitted in fulfillment of the requirements
for the degree of
Doctor of Philosophy

AUGUST 2018

ACKNOWLEDGEMENT

Bismillahirrahmanirrahim. First and foremost, I would like to express my gratitude to Allah S.W.T, the Most Gracious and the Most Merciful for His blessings and for giving me strength, thoughts, good health that allow me to complete the study. In general, this work cannot be successfully completed without continuous assistance and cooperation from many individuals. Specifically, I would like to thank my main supervisor, Professor Sr Dr. Mastura Jaafar for her valuable comments, advice, support, patience and guidance throughout my journey to finish the doctorate study. I would also wish to thank my former co-supervisor, Associate Professor Wan Mariah Wan Harun, for her constant belief and advice, which has illuminated my entire research path.

Special thanks to my beloved parents and siblings for their unrelenting support and prayers to ensure I will keep on persisting and pursuing my dreams. In addition, I would love to extend my heartfelt appreciation to my friends and other related persons who have, in one way or another, offered me invaluable assistance and advice. In particular, I am so grateful to Ministry of Health for giving me permission and unwavering support to conduct this research. In that case, I have also acknowledged the warm help and cooperation from all the participants of my research study.

Finally yet importantly, I am deeply indebted to Kementerian Pengajian Tinggi for financially supporting my study and to National Institute of Valuation (INSPEN) for giving me such opportunity to participate in research grant by funding the project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

BCA	Building and Construction Authority
CDC	Checklist Development Checklist
COMASS	Comprehensive Maintainability Scoring System
DLP	Defect Liability Period
HSS	Hospital Support Services
MDC	Maintainability Design Criteria
M&E	Mechanical & Electrical
MoH	Ministry of Health
PU	Polyurethane
PWD	Public Work Department

PENILAIAN KRITERIA REKABENTUK KEBOLEHSENGGARAAN TERHADAP BANGUNAN HOSPITAL KERAJAAN

ABSTRAK

Kebolehsenggaraan bangunan adalah satu aspek penting yang perlu dipertimbangkan untuk mencapai prestasi bangunan yang baik dan mengurangkan kos penyelenggaraan. Kriteria RekaBentuk Kebolehsenggaraan (MDC) adalah keperluan rekabentuk khusus yang menekankan aspek kemudahan penyelenggaraan dan meminimakan kecacatan bangunan ke arah pencapaian prestasi bangunan yang optimum dengan kos yang minimum sepanjang kitaran hayat bangunan. MDC adalah salah satu bidang utama untuk meningkatkan pengurusan bangunan hospital kerajaan. Objektif kajian ini ialah 1) menilai MDC di bangunan hospital kerajaan, 2) meneliti aplikasi MDC di bangunan hospital kerajaan, dan 3) membina senarai semakan MDC untuk bangunan hospital kerajaan. Untuk mencapai objektif kajian, kaedah kajian kes terdiri daripada penilaian dokumen sekunder, temubual kumpulan fokus, temubual tinjauan dan temubual bersemuka telah dilakukan untuk mendapakan maklumat mengenai kes-kes yang terlibat. Penilaian pakar juga dilakukan untuk mengesahkan senarai semakan. Dua hospital kerajaan telah dipilih iaitu Hospital Sultanah Bahiyah dan Hospital Sultan Abdul Halim. MDC untuk hospital kerajaan telah diukur melalui kebolehcapaian, kesesuaian bahan dan aspek persekitaran. Data telah dianalisa menggunakan kaedah analisis berorientasikan kes and analisis merentas kes. Penemuan objektif pertama menunjukkan tahap MDC adalah berbeza di bangunan hospital kerajaan yang memerlukan penambahbaikan untuk mencapai kebolehsenggaraan yang tinggi. Objektif kedua mendedahkan ketidaksempurnaan

aplikasi MDC di bangunan hospital kerajaan disebabkan kurangnya kesedaran dan pengetahuan mengenai kebolehsenggaraan, tidak wujud prosedur yang formal untuk membimbing industri mengenai MDC dan tiada klausa mengenai MDC di dalam dokumen kontrak. Objektif ketiga ialah untuk membina senarai semakan rasmi sebagai prosedur alternatif yang menekankan MDC diperingkat rekabentuk dan merangkumi keperluan rekabentuk MDC yang sesuai untuk bangunan hospital kerajaan. Kesimpulannya, kajian mendapati MDC adalah penting untuk mencapai prestasi bangunan yang baik, mengurangkan kos penyelenggaraan, mengurangkan kecacatan bangunan dan meningkatkan keselesaan pada penghuni di bangunan hospital kerajaan.

ASSESSMENT OF MAINTAINABILITY DESIGN CRITERIA ON GOVERNMENT HOSPITAL BUILDINGS

ABSTRACT

Building maintainability is an indispensable aspect that needs to be considered in order to achieve good building performance and reduce maintenance cost. Maintainability Design Criteria (MDC) is a specific design requirement to address ease of maintenance work aspects and minimise the occurrence of building defects towards achieving optimal building performance within minimum cost throughout the building's life cycle. MDC is one of the key areas to improve the management of government hospital buildings. The objectives of the study are 1) to assess the MDC in government hospital buildings, 2) to examine an application of MDC in government hospital buildings, and 3) to develop a checklist of MDC for government hospital buildings. To achieve the objectives, the case study method consists of secondary documents reviewed, focus group interview, survey interview and face-to-face interview to elicit the information regarding the cases. The experts' survey to validate the checklist was conducted. Two government hospitals namely Hospital Sultanah Bahiyah and Hospital Sultan Abdul Halim were selected as case studies. MDC for government hospitals has been measured through accessibility, suitability of materials and environmental. Data were analysed using case-oriented analysis and cross-case analysis. The findings of first objective shows there are different levels of MDC's condition in government hospital buildings which require improvement to achieve higher maintainability. The second objective reveals an improper application of MDC in government hospital buildings due to lack of awareness and knowledge on maintainability, non-existence of formal procedure to guide the industry on the MDC

and the missing clause on MDC in the contract documents. The third objective is to develop the formal checklist as alternative procedure to address MDC at the design stage and encompasses relevant design provision of MDC for government hospital buildings. In conclusion, the study found MDC is significant in achieving good building performance, reducing maintenance cost, diminishing the occurrence of defects and enhancing comfort to the end users in government hospital buildings.

CHAPTER 1

INTRODUCTION

1.1 Introduction

This chapter delineates the introduction of the research. The first section of this chapter elaborates on the background of the study comprising the maintainability concept, building maintainability, maintainability design criteria (MDC) and the importance of maintainability for government buildings. The next description entails the research problems, aim, objectives and research questions. Subsequently, the study outlines the definition of key terms while the methodology of this study is briefly explained before portraying the outline of this thesis as the final wrapping up.

1.2 Background of Study

The introduction of maintainability concept started in the year 1954 by military services in the United States (Blanchard and Lowery, 1969). Originally, the term maintainability is measured by *"mean time to repair (MTTR)"* which focused on time aspect in completing the task to enhance the efficiency of maintenance work (Utez, 1983; Ikpo, 2009). Ease of replacement works such as disassembly, reassembly, localisation and isolation are the significant factors in maintainability analysis (Cunningham and Cox, 1972; Blanchard, Verma and Peterson, 1995). In addition, maintainability concept correlates extensively with inherent design characteristics. It requires the execution of equipment design and ease of maintenance including

availability, equipment, safety, economy and accuracy (Blanchard and Lowery, 1969). The Department of Defense (1988) defined maintainability as:

"A characteristic of design and installation which measures of the ability of an item to be retained in or restored to a specified condition when maintenance is performed by personnel having specified skill level and using prescribed procedures and resources at each prescribed level of repair" (p. 1-1)

The definition above of maintainability shows the significance of design towards the item's performance and maintenance activities. This concept has been used widely in engineering fields such as software (Muthanna, Kontogiannis, Ponnambalam and Stacey, 2002), chemical (Pistikopoulos, Vassiliadis and Papageorgiou, 2000), automotive (Abdullah, Yusoff and Ripin, 2006), automation (Yu, Peng and Liu, 2011), mechanical (Kumar, Khan and Ghandi, 2011) and civil aircraft (Lu, Zhou and Li, 2015). Nevertheless, there is a contrary segment for incorporating maintainability into buildings context. Building maintainability is more complex compared to engineering because it has relationships with large numbers of building components, design, construction activity and exposure condition (Das, Chew and Poh, 2010).

Due to these dissimilarities, it has motivated many scholars to explore on building maintainability which can be seen through the burgeoning body of literature on the significance of maintainability in achieving cost savings and good building performance (Feldman, 1975; Briffett, 1990; Dunston and Williamson, 1999; Arditi and Nawakorawit; 1999, Silva, Dulaimi, Ling and Ofori, 2004; Chew, Tan and Kang,

2004; Chew, Silva and Tan, 2004a, 2004b, 2004c; Das et al. 2010; Silva and Ranasinghe; 2010a, 2010b; Silva, Ranasinghe and Silva, 2016). The definition of building maintainability is a design characteristic which incorporates ease of maintenance work aspects, being implemented towards achieving optimal building performance with minimum cost throughout a building's life cycle. There are several particular areas of building maintainability that have been explored by researches such as materials and building elements, maintainability design criteria, strategy for building maintainability improvement and decision making tools.

The importance of maintainability has encouraged previous studies such as Chew et al. (2004c) and Silva and Ranasinghe (2010a) to explore and identify factors that affect building maintainability. Despite identifying the factors, it is relevant to use and address these factors in appropriate ways in order to achieve higher maintainability. Therefore, the concept of Maintainability Design Criteria (MDC) is adopted in this thesis. The MDC for this study is defined as a specific design requirement to address ease of maintenance work aspects and minimise the occurrence of building defects towards achieving optimal building performance within minimum cost throughout a building's life cycle. The study on MDC is valuable and beneficial to allow the success of design for maintainability in construction industry.

The design for maintainability approach has induced the governments around the world such as UK, Australia, Canada, Singapore and other developed countries to emphasise the maintainability concept in managing public buildings. For example, in Malaysia, Government Total Asset Management Manual *(Manual Pengurusan Aset Menyeluruh, MPAM)* has been launched in March 2009 in order to provide the best

guideline and strategy to all government agencies in managing their assets systematically and effectively (Government of Malaysia, 2009). Additionally, the Malaysian government has instructed all its agencies to carry out the maintenance aspects at the very early stage in order to avoid risk of higher maintenance cost in the long run (Mohd-Noor, Hamid, Abdul-Ghani and Haron, 2011). It shows that maintainability has resulted in easing the maintenance activities as it is crucial to managing the government buildings as future investment.

In Malaysia, the government has outsourced the maintenance services through privatisation programme (Yusof and Bhattasali, 2009). The objectives of this agenda are to reduce financial burden and administration of government, and to enhance efficiency and productivity of the sector (EPU, 1985). Through this programme, the government would be able to pay close attention on the growth of building operation and deliver good services to the public. In 1996, the Government of Malaysia took the initiative to implement a major privatisation project for the provision, maintenance and management of Hospital Support Services (HSS) of government hospitals throughout the country which comprises of five packages of Facility Management Services (FMS) that consist of Facility Engineering Management Services (FEMS), Biomedical Equipment Management System (BEMS), Cleaning Services (CLS), Linen and Laundry Services (LLS), and Healthcare Waste Management Services (HWMS) (Fan, 2016).

The HSS of government hospitals through the privatisation project does not cover rectification work of building defects. In the lens of hospital operation, the occurrence of defects in hospital buildings will affect the level of effectiveness of

treatment and efficiency of hospital operation (Sherif, 1999). Hospital environment requires a set of buildings and facilities that are defect-free. Besides that, building defects has a close relationship with the poor performance of physical parameter (Shohet, 2003; Grussing, Uzarski and Marrano, 2009; Das et al. 2010) and the increase of the maintenance cost (Kian, 2001). The bad consequences of building defects could ruin the government mission.

Building defects are normally known as building maintainability problem (Chew et al., 2004; Chew et al., 2004a, 2004b, 2004c; Ikpo, 2009; Silva and Ranasinghe, 2010a, 2010b; Das and Chew, 2011). The concept of maintainability is to tackle maintenance problems initiated from the design. In addition, the concept of maintainability is somewhat obligatory, able to promote efficiency of maintenance work whereby ease of maintenance is applied (Lau and Ho, 2010). Design for maintainability allows the government to achieve its aims from the beginning of the building project development.

The great potential of maintainability in achieving the government's goals is it emplaces specific demands on the government as the sole owner to develop an appropriate MDC for government hospital buildings. Building laws such as Uniform Building by-Laws 1984 (Laws of Malaysia, 2006a) and Street, Drainage and Buildings Act 1974 (Laws of Malaysia, 2006) do not address the elements of MDC. Thus, it is crucial to identify appropriate MDC for government hospital building in order to achieve higher building maintainability that has been supported by Chew et al. (2004c) and Silva and Ranasinghe (2010a). Besides that, to address the MDC, it needs to be supported by an appropriate checklist. A checklist is a formal procedure which helps

in assisting the designer to address the maintainability properly (Meier and Russell, 2000; Kumar, Galar, Parida, Stenstrom and Berges, 2013; Building and Construction Authority (BCA), 2016). The importance of a checklist has been highlighted by Meier and Russell (2000) without proposing a proper checklist.

Two government hospital buildings in Malaysia have been chosen as study cases for this research. The cases involve Hospital Sultanah Bahiyah, Alor Setar and Hospital Sultan Abdul Halim, Sungai Petani. Both hospitals are tertiary care hospitals and high-rise buildings. In building maintainability context, height is four times more significant compared to the location of the building (Das et al, 2010) because of higher maintainability challenges (Silva et al., 2016).

Both hospitals are located at the northern part of Peninsular Malaysia. These two hospitals were constructed and completed almost at the same time, i.e., Hospital Sultanah Bahiyah was completed in February 2007, slightly a few months later than Hospital Sultan Abdul Halim which was completed in July 2006. The cost for development project of Hospital Sultanah Bahiyah is RM 560 million while for Hospital Sultan Abdul Halim, the cost is about RM468 million. Both hospitals experienced delay in completing the projects because of factors such as changes in design for Hospital Sultanah Bahiyah (Ministry of Work, 2007a) and shortage of skilled workers for Hospital Sultan Abdul Halim. Additionally, the issues of ceiling collapse at Hospital Sultan Abdul Halim were reported by Ministry of Work (2007b). The Ministry of Health Malaysia has outsourced the HSS of both hospitals to Faber Medi-Serve Sdn Bhd as an appointed company for the northern region of Peninsular Malaysia.

1.3 Problem Statement

The clients as the project investors are intolerant towards poor performance or failure of a built facility which would affect the loss of revenue, undervalue stocks and spoil the reputation of such organisations (John, Liyanage and Clements-Croome, 2010). Buildings are a large stock in most of the developed and developing countries because it has a long life span at least for several decades (Grussing and Liu, 2014). However, the investment in public building does not focus on profitability since it is more towards meeting various social and public demands (Kouzmin, Loffler, Klanges and Korac-Kakabadse, 1999). Thus, it is challenging to the government as the building owner to keep up a good building through continuous monitoring of maintenance works in order to ensure the success of building investment.

Since the last few decades, many scholars have highlighted the challenges confronted by all countries around the globe with problems of shrinking in maintenance budget but rising in maintenance cost (Seeley, 1987; Barbour Index, 1998; Baldry, 2002; Chew et al., 2004 ; Chanter and Swallow, 2007; Ali, 2009; Boussabaine, Sliteen and Catarina, 2012). According to the Building and Construction Authority (BCA) (2000), the cost for maintenance in Singapore has gone up to triple from the initial projection within 10 years. In Malaysia, the government had allocated a budget of RM 296 million for maintenance in the Eighth Malaysia Plan 2001-2005 (Malaysia, 2001), and then the rising of budget allocation for maintenance had almost quadrupled to RM 1,079 million in Ninth Malaysia Plan 2006-2010 (Malaysia, 2006). However, the allocation budget for maintenance in Tenth Malaysia Plan 2011-2015 (Malaysia, 2010) had decreased to RM 500 million only. It shows that the Malaysian

government also experiences a problem in the shrinking of maintenance budget and need a solution to reduce the maintenance cost.

Consideration of maintainability at the design stage has been highlighted as one of the significant ways to reduce the maintenance cost. (Chew and Silva, 2004; Hassanain, Al-Hammad and Fatayer, 2013). Thus, maintainability has grown to a paramount importance since the government has spent a lot of money investing on public buildings. However, maintainability is not a favourite aspect to be considered at the design stage (Aris, 2006). The designers do not realise the occurrence of building defects which could derive from the drawing board (Arayela and Adams, 2001). The occurrence of building defects could be one of the consequences of neglecting the maintainability.

Normally, the process of rectification of building defects will be solved by the maintenance team without involvement of designers (Chong and Low, 2006; Silva et al., 2012; Hassanain et al., 2013). The detachment of design team from the post occupancy stage does not allow them to receive information via any complaints or feedbacks on the design issues (Aris, 2006). As a result, it causes a lack of knowledge to the designer on the importance of design for maintainability.

Lack of knowledge transfer on maintainability between designer and maintenance has caused incapability to shift the standard design practice in Malaysia (Kanniyapan, Mohammad, Nesan, Mohammed, Abdullah, Asmoni and Ganisen, 2015). Ismail and Mohamad (2013) argue on the absence of formal procedures in current design practice to incorporate the maintainability requirements. Meier and

Russell (2000) and Building and Construction Authority (BCA) (2016) had elucidated the use of proper methods such as checklists to support maintainability program for the designer. Thus, there is a great necessity to have a checklist as a formal procedure to allow the designer to address the maintainability requirements successfully and elevate the standard design practice.

The goal of a government hospital building is to provide medical services and patient care to the public. A hospital environment should be clean, conducive and patient-friendly. According to Iyagba (2005), poor building maintenance can create unsafe places and allergic-like reactions to the people. Therefore the designer could help to provide clean hospital environments by implementing design for maintainability at hospital buildings.

Every building carries different functions which will have different issues to be settled. For instance, research done by Chew et al. (2004c) and Silva and Ranasinghe (2010a) have listed a few design factors that may affect the maintainability of buildings. However, both of them have also addressed different design factors depending on area of the study and types of buildings. It expresses that every building would have its own MDC. It is noteworthy to have feedbacks from the maintenance team to identify the appropriate MDC which meets the building functions.

There are plenty of studies in relation to maintainability. Most of the scholars around the world tend to focus on, for example (1) residential buildings (Chew et al, 2004a; Chew, Silva, Tan and Das, 2006; Silva and Ranasinghe, 2010a, 2010b; Silva et al., 2016), (2) institutional buildings (Chew et al., 2004a, 2004b, 2004c; Chew et al.,

2006), (3) commercial (Chew et al., 2004a, 2004b, 2004c; Chew et al., 2006; Silva and Ranasinghe, 2010b; Das et al., 2010; Das and Chew, 2011; Silva et al., 2016), (4) industrial (Chew et al., 2004a, 2004b, 2004c; Chew et al., 2006) and (5) mixed development including hospitals (Silva et al., 2016). According to Silva et al. (2016), the design risk factors that could affect high rise buildings including hospitals are architectural and design, accessibility, materials and spare parts, maintenance requirements, characteristic, environment and exposure, and user requirement and changes. Based on the literature review, none of the previous studies conducted on MDC in government hospital buildings specifically. Thus, it has drawn the intention of the researcher to fill the gaps and motivation to conduct a study on MDC for government hospital buildings which benefits in good building management.

1.4 Research Questions

The main research question of this study is: How do the design criteria for maintainability affect in managing government hospital buildings in Malaysia? Four sub research questions of the study are investigated as stated below:

1. How was the condition of MDC in government hospital buildings?
2. What are the issues of MDC in government hospital buildings?
3. How was the MDC applied in the design of government hospital buildings?
4. What are the relevant design provisions of MDC for government hospital buildings?

1.5 Research Objectives

The aim of the research is to investigate the design criteria for maintainability which would affect the management of government hospital buildings. Overall, this research carries three objectives as stated below.

1. To assess the MDC in government hospital buildings;
2. To examine an application of MDC in government hospital buildings;
3. To develop a checklist of MDC for government hospital buildings.

1.6 Definition of Key Terms

Maintainability is a significant and indispensable facet for long term building investment. Building maintainability definition used in this study is based on Feldman (1975), Dunston and Williamson (1999) and Chew et al. (2004). Building maintainability is defined as a design characteristic which incorporates ease of maintenance work aspects in achieving optimal building performance with minimum cost throughout a building's life cycle.

The term 'government hospital building' refers to the hospital owned by the Ministry of Health Malaysia (MoH).

The study has adapted definition of MDC from Blanchard et al. (1995) to incorporate the building maintainability. This study defined MDC as a specific design requirement to address ease of maintenance work aspects and minimise the occurrence

of building defects towards achieving optimal building performance within minimum cost throughout a building's life cycle.

The MDC for this study was measured through three elements of accessibility, suitability of materials and environmental aspects. Accessibility's definition used in this study is based on Gaoliang et al 2(010) and Lu et al. (2015). Accessibility is defined as the ability of maintenance personnel to reach the work area and perform their job effectively with safety concern, adequate space and using standard tools.

The definition of suitability of materials is based on Building and Construction Authority (BCA) (2016) which refers to the ability of an item to resist defects from normal wear and tear, and perform the intended function throughout the design life which can minimise the frequency of maintenance work.

The environmental aspects is defined as macro-environment from a study conducted by Silva and Ranasinghe (2010a) namely, temperature, rainfall, wind, sunlight and also building location that may influence the occurrence of building defects.

Definition of checklist is adapted from Building and Construction Authority (BCA) (2016). A checklist of MDC is defined as formal reference comprising of design provision for maintainability that applies to government hospital buildings.

1.7 Methodology

The study explores the design criteria for maintainability that will affect in managing government hospital buildings in Malaysia. To develop the exact meaning of this study, it is critical to elicit the maintenance perspective and design team perspective. The purposeful sampling technique has been applied to access to the expert participants. The selection of participants is explained in section 3.6. To obtain the data, this study will use qualitative data collection approach such as documentation and interview (Creswell, 2013).

The purpose of documentation process is to acquire information on the types of building defects from the maintenance records which specify the actual building's condition and the maintenance issue (Department of Defense, 1988; Meier and Russell, 2000; Chong and Low, 2006; Silva et al., 2016). Thus, this study will review the available documents at government hospitals after receiving the permission from Ministry of Health Malaysia and the hospital's director. All the gathered information will be utilised to develop a questionnaire form for the interview sessions.

After completing the data collection through the documentation process, the researcher will conduct a focus group interview and survey interview with maintenance participants from both hospitals. The participants were the engineers of hospital and Faber Medi-Serve Sdn Bhd. The purpose of the interview sessions is to obtain their perceptions and experience in managing government hospital buildings and the condition of MDC for each of the selected hospitals.

The next method entails face-to-face interview session with project team members who were involved in the development of both hospital buildings. The aim of this stage is to identify whether MDC had been considered and applied at the design stage and to gain their perception about the rising issues of government hospital buildings. The main parties are the representative of client of Ministry of Health Malaysia (MoH) and Public Work Department Malaysia (PWD), main contractors' representatives including architect coordinator and project manager, and the main contractor’s designers that consist of architect and medical planner.

Lastly, the study will select a few experts of the industry to validate the relevant design provisions on the appropriate MDC for government hospital buildings as the aim of the study is to propose a checklist. This study has adapted two types of checklists namely Checklist Development Checklist (CDC) from Stufflebeam (2000) for steps in developing a checklist while for the content of checklist, the study has adapted it from Design for Maintainability of Building and Construction Authority (BCA) (2016). In addition, the contents of the checklist also include the relevant literature and findings of the study.

1.8 Thesis Outline

This thesis is organised into six chapters excluding appendices and the references. Chapter One focuses on the introduction of the study that consists of background of the study, research problems, aim and objectives, research questions, definition of key terms, methodology and outline of the thesis.

For Chapter Two, the elaboration dwells on building maintainability and design criteria comprising of definition of building maintainability, the evolution of building maintainability study, maintainability design criteria (MDC), design for maintainability and design for hospitals. Then, the study elaborates the guidelines for hospital design. Then, it continues with the concise description on government hospital buildings in Malaysia encompassing building maintainability problem.

Chapter Three provides profound details of the methodology of the research that consists of interpretive philosophical, case study as qualitative research approach, research design for the case study, selection of case studies, selection of participants, data collection process, questionnaire design, data analysis, validity and reliability and checklist development. After that, Chapter Four presents the related findings and analysis of the result from primary and secondary data of both cases.

Chapter Five deliberates on the analysis and discussion of the results, findings and literature review according to research objectives. Finally, Chapter Six highlights the achievement and main findings, contribution of the study, limitation and recommendation for further research.

1.9 Summary

On the whole, the chief aim of this study is to investigate the MDC for government hospital buildings in Malaysia. This chapter explains the whole study in a precise manner. The second chapter will further elaborate on building maintainability and design criteria.

CHAPTER 2

BUILDING MAINTAINABILITY AND DESIGN CRITERIA

2.1 Introduction

This chapter comprises of two parts of literature review. Part one elaborates on the definition of building maintainability and its development area by focusing on the materials and building elements, MDC and strategy for building maintainability improvement. Following that, the study explains on the three major groups of MDC, i.e., accessibility, suitability of materials and environmental aspects. Furthermore, this chapter also describes on the design for maintainability and other related designs in the context of hospital buildings. Part two will dwell on government hospital buildings in Malaysia and building maintainability problems.

2.2 Definition of Building Maintainability

Feldman (1975) referred to the concept of building design for maintainability as "*ease of maintainability*". He is the earliest scholar to define building maintainability as "*the condition of an item or a* surface *that permits its repair, adjustment, or cleaning with reasonable effort and cost*" (p. 1). The definition refers to the ability of using basic preparation through the utilisation of suitable items for easy maintenance with minimum cost (Feldman, 1975). In the context of constructability, Dunston and Williamson (1999) derived the definition of optimal maintainability of building facilities as "*the design characteristic which incorporates function, accessibility, reliability and ease of servicing and repair into all active and*

passive system components that maximises costs, and maximises benefits of the expected life cycle of a facility" (p. 56). This definition is more comprehensive as it covers ease of maintenance features as a result of effective maintenance cost and building life span. Another researcher who studied on the building performance model came out with a different definition of building maintainability that is *"achieving optimum building performance throughout the building life span within minimum life cycle cost"* (Chew et al., 2004, p. 581)

It can be summarised that, from the definitions given by those authors, building maintainability could be defined as a design characteristic which incorporates ease of maintenance work aspects in achieving optimal building performance with minimum cost throughout a building's life cycle. The importance of considering all aspects is to ensure the lifespan of the building can be prolonged and the building can function as its design.

2.3 The Evolution of Building Maintainability Study

The development of building maintainability study started in the 1975 by Edwin B. Feldman (Feldman, 1975) who appreciated the benefits of implementing maintainability at the building design stage. Since that time, a number of scholars have begun to show their concerns on building maintainability study such as Dunston and Williamson (1999), Meier and Russell (2000), Her and Russell (2002), Silva et al. (2004), Chew et al. (2004), Chew et al. (2004a, 2004b, 2004c), Chew et al. (2006), Ikpo (2009), Chew and Das (2009), Das et al. (2010), Silva and Ranasinghe (2010a,

2010b), Das and Chew (2011), Ismail and Mohammad (2013) and Silva et al. (2016). Each of them had their own interest in diverse fields.

Based on the literature review, Table 2.1 shows the list of scholars who have conducted a research on particular areas of building maintainability by focusing on four areas such as 1) materials and building element (Feldman, 1975; Chew and Das, 2009), 2) maintainability design criteria (Chew et al., 2004c; Silva and Ranasinghe, 2010a), 3) strategy for building maintainability improvement (Meier and Russell, 2000; Her and Russell, 2002; Silva et al., 2004; Ikpo, 2009) and 4) decision making tools, for instance, Artificial Neural Network (ANN) (Chew et al., 2004; Chew et al., 2004a, 2004b; Chew et al., 2006; Silva and Ranasinghe, 2010b), Analytical Hierarchy Process (AHP) (Das et al. 2010), Ensemble Neural Network (ENN) (Silva et al., 2016), Failure Mode Effect and Criticality Analysis (FMECA) (Das and Chew, 2011) and manufacturing product design such as Robust Engineering (RE) (Ismail and Mohamad, 2013).

Table 2.1: Building Maintainability Areas of Study

Author & Year	Area			
	Materials and building element	Maintainability design criteria	Strategy for building maintainability improvement	Decision making tools
Feldman (1957)	√			
Dunston and Williamson (1999)				√
Meier and Russell (2000)			√	
Her and Russell (2002)			√	
Silva et al. (2004)			√	
Chew et al. (2004)				√
Chew et al. (2004a)				√
Chew et al. (2004b)				√
Chew et al. (2004c)		√		
Chew et al. (2006)				√
Ikpo (2009)			√	
Chew and Das (2009)	√			
Silva and Ranasinghe (2010a)		√		
Silva and Ranasinghe (2010b)				√
Das et al. (2010)				√
Das and Chew (2011)				√
Ismail and Mohamad (2013)				√
Silva et al. (2016)				√

Source: Compiled by the author

Table 2.1 shows the development of building maintainability study. The requirement to understand building materials and elements characteristics had been initiated by Feldman (1975) before it was followed by analysing maintenance cost data as a basis to develop decision making tools which was highlighted by Dunston and Williamson (1999). After that, the concern on planning process for implementing maintainability study took up in early 2000. The continuity of comprehensive studies on building maintainability has been growing on scattered areas as efforts are being done by previous scholars for better future building development and contribution to knowledge. Scholars such as Chew et al. (2004), Chew et al. (2004a), Chew et al.

(2006), Das et al. (2010), Silva and Ranasinghe (2010b) and etc. had come out with decision making tools towards achieving goals in terms of improving building performance, cost effective in managing building assets and motivation for construction industry players in designing a good building.

Amidst four study areas depicted in Table 2.1, this research will focus mainly on the 1) materials and building elements, 2) MDC and 3) strategies for building maintainability improvement due to the fact that the goal of this research is to develop design criteria for maintainability of government hospital buildings. Thus, the elaboration on decision making tools has been excluded because this area focuses on developing tools for measuring maintainability which is not suitable for the study.

In the maintainability study, selection of the right materials and building elements play a significant role to achieve higher maintainability by minimising the defects of buildings as well as providing conducive building performance. Next, the maintainability design for hospital buildings can also be proposed through maintainability design criteria study. Besides that, the suitable procedure or practice for maintainability practical application can be attained through the study of strategy for building maintainability improvement. The detailed elaboration of each of the selected studies areas are discussed as follows.

2.3.1 Materials and Building Elements

The first area of study focused on selection of materials and building elements. Generating the idea on how to achieve maintainability in terms of *"reasonable effort and cost"* by considering material selection at the early development was driven and established by Feldman (1975). Likewise, the result of Chew et al.'s (2004a) study verified that the material which is easy to clean and has minimal inspections leads to minimum maintenance cost. Other scholars also highlighted the significance of material selection for maintainability such as Chew et al. (2004), Chew et al. (2004b, 2004c), Chew et al. (2006), Das et al. (2010), Silva and Ranasinghe (2010a, 2010b), Das and Chew (2011). They have used materials as a fundamental to widen the scope and produce comprehensive building maintainability studies.

Issues on building defects, specifically in relation to the materials selection has motivated the National University of Singapore and Building and Construction Authority (BCA) to develop Defect Library and Material Manual sections for "*Comprehensive Maintainability Scoring System (COMASS)"* (Chew and Das, 2009). This system has proper databases that consist of a broad collection of building defects and information on defective building materials and material guidelines (Chew and Das, 2009). These databases will help the industry players to make the right decision by referring to the defects data for each material. Materials selection is significant to the occurrence of building defects; building defects is normally regarded as building maintainability problems.

In terms of selecting building elements, the previous researchers such as Feldman (1975), Chew and Das (2009) and Silva et al. (2016) have categorised the selection of building elements based on their scope of the study. For example, the selection of building elements by Feldman (1975) made general explanation on maintainability to all building elements such as exterior building surfaces, roof, stairs, interior (floors, walls, ceilings), elevators, furniture, fixtures, fenestration, restrooms, plumbing and piping. While Chew and Das (2009) who studied on COMASS, conducted at commercial buildings which excluded building interior elements. Thus, COMASS has selected nine major building elements encompassing wet area, façade, basement, roof, sanitary-plumbing, HVAC, elevator, electrical and fire protection (Chew and Das, 2009). In contrast, Silva et al. (2016) identified four major building elements comprising roof, exterior wall and basement or ground floor and also interior. The selection of major building elements affects level of maintainability (Das et al., 2010).

The discussion above reveals the differences in terms of selection of major building elements based on types of building and study preferences. Thus, this study adapted the work by Silva et al. (2016) for major building elements for government hospital buildings that are roof, exterior ceiling and wall and interior ceiling, wall and floor.

2.3.2 Maintainability Design Criteria

The second area of study focuses on Maintainability Design Criteria. Chew et al. (2004c) identified six key building design factors to achieve higher maintainability in wet areas for non-residential high-rise buildings namely 1) water-tightness, 2) spatial, 3) integrity, 4) ventilation, 5) material and 6) plumbing. Later, Silva and Ranasinghe (2010a) extended the study to the whole condominium building by proposing five factors to achieve higher maintainability which are: 1) design for adequate safety, 2) design for maintenance needs, 3) design for environment, 4) plan for easy maintenance and 5) design for efficient access. The researches above were in different building areas in which the first focuses on wet area while the second study focuses on the whole building. This justified the different design factors derived from those studies. Therefore, it is important to specify the area of study in developing MDC.

2.3.3 Strategy for Building Maintainability Improvement

The third study area is on strategy for building maintainability improvement. There are many suggestions by previous studies such as Meier and Russell (2000), Her and Russell (2002), Silva et al. (2004) and Ikpo (2009) to achieve higher maintainability of buildings. The most highlighted strategies are life cycle cost (LCC), guideline and checklist as initiatives to enhance ease of maintenance work and cost-effective life cycle.

Blanchard et al. (1995) has coined up building life cycle cost (LCC) as one of the main factors for improving maintainability. The consideration of maintenance cost in the context of life cycle cost affects the maintainability level which works at minimum cost. The significance of life cycle cost has motivated a few other studies to apply life cycle cost (LCC) in deriving scoring system such as Chew et al. (2004a, 2004b), Silva and Ranasinghe (2010b) and Silva et al., (2016) since life cycle cost can be set at the minimum level of risk (Chew et al., 2004a). However, life cycle cost analysis for maintainability is difficult to handle in analytical method or linear method because it associates with maintenance cost such as cleaning, repair, and replacement (Chew et al., 2004a).

Developing a guideline for maintainability is another alternative. Previous studies such as Her and Russell (2002) and Silva et al. (2004) have highlighted on providing guideline as one of the methods to ensure success in implementing maintainability at building design stage. There is a necessity for clients to make an effort from the beginning of project development especially at design stage in order to achieve higher maintainability. For instance, National Aeronautics and Space Administration (NASA) has provided guidelines for the maintainability programme to ensure the third-party contractor implements the right procedure at the project level (Her and Russell, 2002). In Singapore, the system of COMASS that consists of building material guideline demonstrates the client's effort to achieve higher maintainability (Chew and Das, 2009). Thus, guideline could be a good instrument to emphasise on maintainability and it requires the concerted involvement from the client to ensure that it will be successfully applied. However, the designer tends to ignore the text of guideline due to the difficulties in interpreting the guideline (Galitz, 1989), as

cited in Russell, Durling, Griffiths and Crum (1997). The compilation of guidelines might contain hundreds of pages, which are derived from academic publications, practical experience and authoritative opinion (Russell et al. 1997). It contrasts with the designer's preference that need quick and easy access such as indexing, contents table and checklist (Galitz, 1989) cited in Russell et al. (1997).

Besides developing the guideline, checklist has also been mentioned by many commentators as one of the proper methods that emphasises maintainability by clients (Meier and Russell, 2000). Meier and Russell (2000) had believed that the clients need to develop formal maintainability work process such as design checklist to support the maintainability programme for designers. The benefit of using checklist is to provide *"quick but rough"* understanding (Kumar et al., 2013). Thus, checklist is the suitable formal procedure to successfully address maintainability by designers.

Checklist is *"used to encourage or verify that a number of specific lines of inquiry, steps or actions are being taken, or have been taken"* (Andrews, 2008, p. 78). The major purpose of checklist is to ensure all requirements for maintainability are successfully addressed at the design stage. Interestingly, checklist could also be utilised as a guidance to assist the clients and designers in incorporating maintainability in design process (Meier and Russell, 2000; Building and Construction Authority (BCA), 2016). For instance, the Ministry of National Development of Singapore, together with Building and Construction Authority (BCA) as the government agency, have made an effort to develop formal Design for Maintainability Checklist. That checklist will be used for clients and architects as formal reference to appropriately address design for maintainability (Building and Construction Authority